

United States Patent

Bross

[15] 3,658,067

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[54] ELECTRO-SURGICAL APPARATUS

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[52] U.S. Cl. 128/303.14

[51] Int. Cl. A61b 17/36

[58] Field of Search 128/2, 303.14-303.18

[56] References Cited

UNITED STATES PATENTS

2,835,254 5/1958 Coles 128/303.14

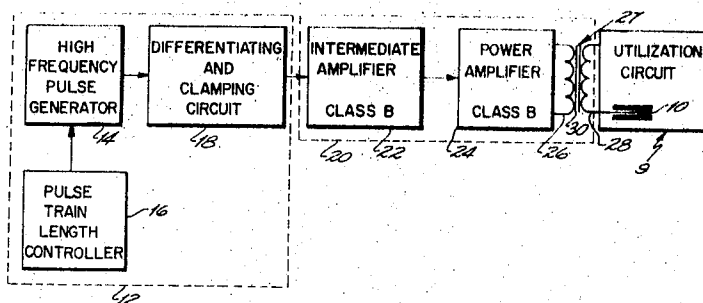
3,089,496 5/1963 Degelman 128/303.14
3,197,612 7/1965 Reich 128/303.14 X

Primary Examiner—L. W. Trapp
Attorney—Wood, Herron & Evans

[57] ABSTRACT

An electro-surgical apparatus including a transistorized source of high frequency pulses, a transistorized class B amplifier responsive to the output of the high frequency pulse source, and a conductive surgical instrument which is inductively coupled to the output of the class B amplifier by a transformer with tightly coupled primary and secondary windings wound on a cup core having a permeability of approximately 2,000.

7 Claims, 19 Drawing Figures



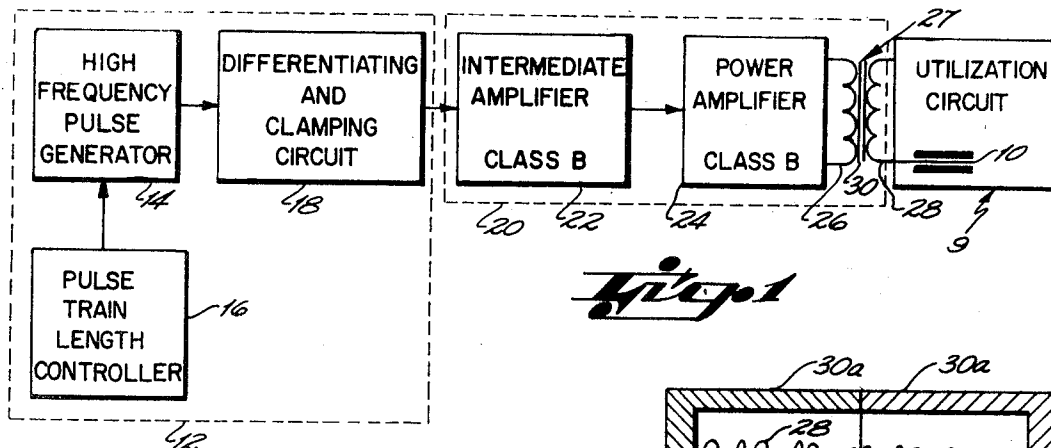


Fig. 1

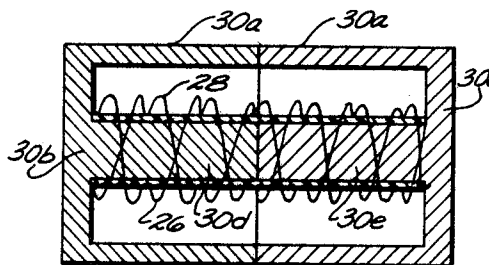


Fig. 3

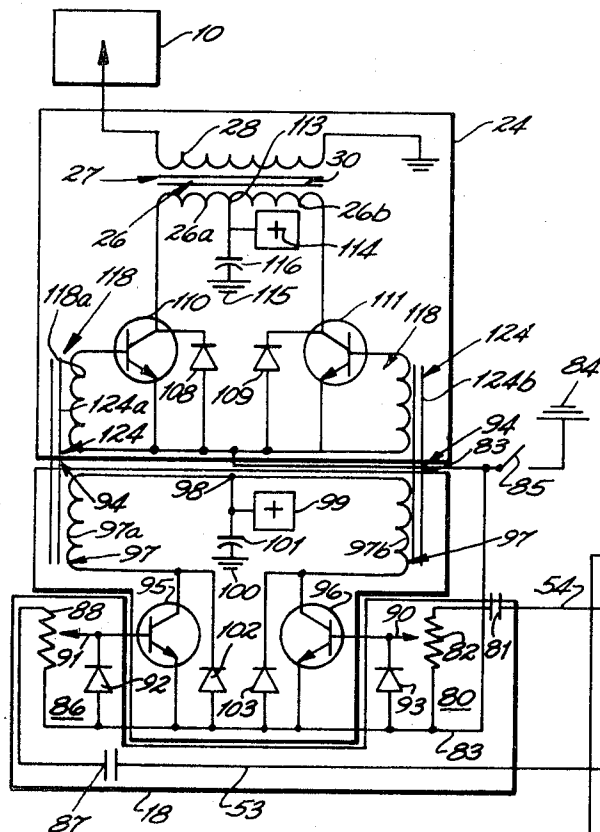
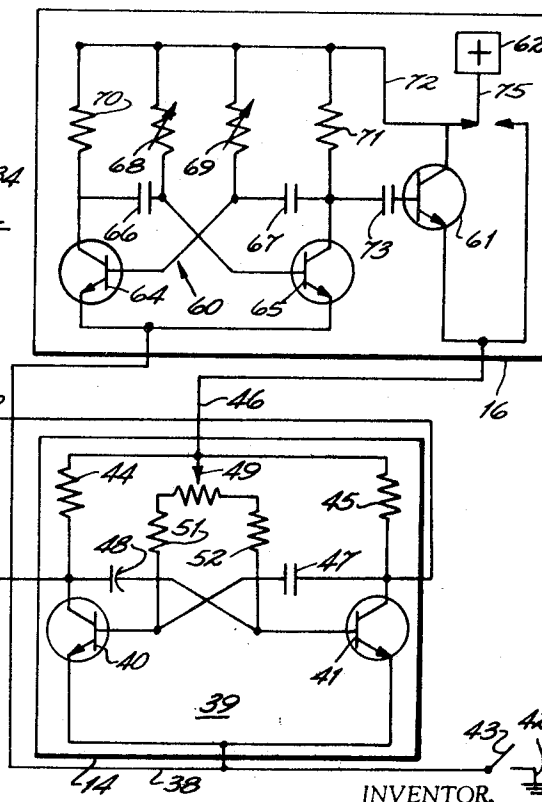


Fig. 2



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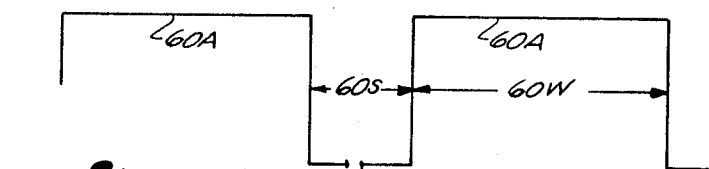


Fig. 4a

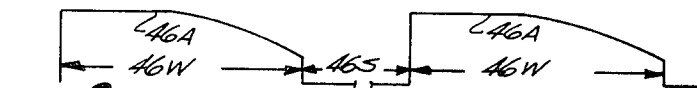


Fig. 4b

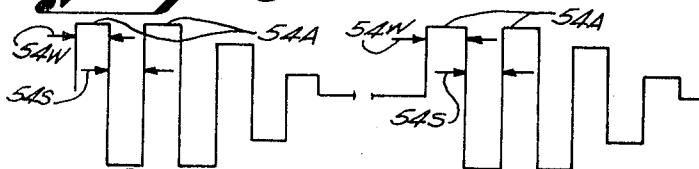


Fig. 4c



Fig. 4d

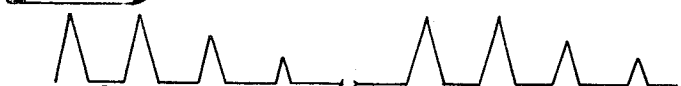


Fig. 4e

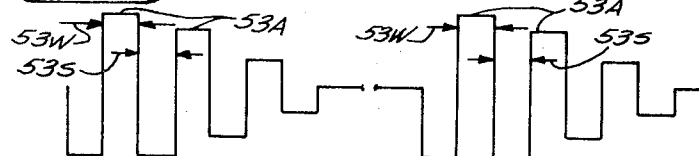


Fig. 4f



Fig. 4g



Fig. 4h

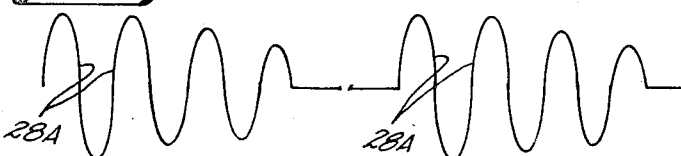


Fig. 4i



Fig. 5a



Fig. 5b



Fig. 5c

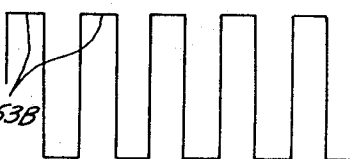


Fig. 5d

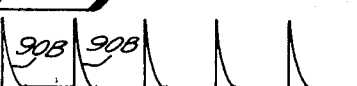


Fig. 5e



Fig. 5f

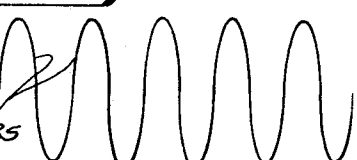


Fig. 5g

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ELECTRO-SURGICAL APPARATUS

This invention relates to electro-surgical apparatus, and more particularly to electro-surgical apparatus of the type in which a conductive surgical instrument is supplied with high frequency electrical signals from a fully transistorized electrical signal generating and amplifying circuit.

Electro-surgical apparatus of the type to which this invention is directed typically include a conductive surgical instrument such as a knife blade or loop electrode, a source of high frequency signals, and an amplifier connected between the signal source and electrode for amplifying the high frequency signals to a useful level and coupling the so amplified signals to the electro-surgical knife to facilitate cutting or coagulation, as desired. The cutting action or coagulation action produced by the instrument at any given point on the tissue is a function of the current density at the interface between the instrument and tissue at the point in question. For different cutting rates or coagulation depths, different current densities are required.

Assuming a specified cutting rate or coagulation depth is desired in a given surgical procedure, the instantaneous current fed to the surgical instrument, in practice, varies over a wide range. Such variation is due to the fact that during the surgical procedure the area of contact between the surgical electrode and the tissue at their interface varies over a wide range. Thus, if current density over the electrode-tissue interface is to be constant throughout the entire surgical procedure to achieve the desired uniformity in cutting rate or coagulating depth, and if the area of the interface in practice varies, then the instantaneous current fed to the surgical electrode must necessarily vary.

Illustrative of the variation in the area of the electrode-tissue interface, and hence of the variation in instantaneous current required to provide constant current densities over interface throughout the entire surgical procedure, is that occurring in surgical procedures known as biopsies wherein a loop electrode is utilized to remove cone-shaped slivers of tissue or flesh for the purpose of providing specimens for microscopic examination. When the loop electrode initially contacts the flesh or tissue, substantially the entire loop is in electrical contact with the tissue, requiring a relatively large instantaneous current to provide the desired level of cutting current density over the entire electrode-instrument interface. As the loop is drawn through the flesh or tissue to, in effect, carve out of the tissue surface the cone-shaped sliver or specimen, the area of contact between the loop and the subject's tissue at their interface gradually decreases until, when the loop is pulled entirely through the tissue, the contact or interface area is zero. If has been found that in the course of removing the cone-shaped sliver of tissue, from the point of initial contact of the loop with the tissue through the point where the loop is withdrawn, the area of the electrode-tissue interface varies by as much as a factor of 10. This, in turn, causes the instantaneous current input to the loop electrode to likewise vary by a factor of 10, assuming the current density at all points of the varying area electrode-tissue interface is to remain constant throughout the entire surgical procedure.

Variations in the instantaneous current input to the surgical instrument, insofar as the amplifier which powers the surgical instrument is concerned, are manifested as variations in the electrical load impedance of the amplifier. Such variations in amplifier load impedance impose stringent operating requirements on the amplifier. Specifically, the amplifier must be designed such that, without adjustment, it supply large currents to the electrode when the electrode-tissue interface is large and the amplifier load impedance low, yet supply low currents to the electrode when the electrode-tissue interface is small and the amplifier load impedance is high. In the past this requirement for adjustment-free variation in amplifier output current over a wide range of load impedances to accommodate different electrode-tissue interface areas encountered in use has been satisfied by using vacuum tube amplifiers which deliver to the electrode the rather substantial current levels required when the electrode-tissue interface area is

large, and which when the electrode-tissue interface is small dissipates substantial amounts of unused current not coupled to the electrode.

While the prior art design approach, wherein large amounts of current are dissipated in the amplifier when the electrode-tissue interface is small, is possible with vacuum tube amplifiers due to the inherent capability of vacuum tube amplifiers to dissipate large amounts of current without destruction or damage, this approach is not the most economical nor does it produce the most compact unit. With the cost and size of solid state amplifier circuitry, such as transistors, significantly less than the cost and size of vacuum tube type amplifiers, it is uneconomical in terms of both money and space to use vacuum tube type amplifiers in electro-surgical apparatus when low cost and compact transistor type amplifiers are available.

Unfortunately, because of the peculiar amplifier load impedance, and hence output current level, variations encountered in use and the amplifier design approaches heretofore used wherein large amounts of current are dissipated when the electrode-tissue interface is small, it has so far not been practical to transistorize the amplifying function in conventional electro-surgical apparatus and realize the money and space economies of transistorization. This impracticality is due, in large part, to the inherent inability of transistors to dissipate the large amounts of current typically dissipated in the tube type amplifiers of conventional electro-surgical apparatus. Thus, while the economies in money and space of transistorization of amplifiers in other applications, such as radio and television receivers, have been realized, such has not been the case in amplifiers used in electro-surgical apparatus of the type described wherein large impedance, and hence current, variations are encountered due to the peculiarities of the surgical procedures in which such apparatus is used.

It has been an objective of this invention to provide electro-surgical apparatus capable of transistorization, thereby reducing the cost of the apparatus and rendering it more compact. This objective has been accomplished in accordance with certain of the principles of this invention by adopting a fundamentally different approach to the design of electro-surgical apparatus. This approach, in essence, involves coupling the amplifier output to the surgical electrode with a step-up transformer having tightly coupled primary and secondary windings wound on a core characterized by a magnetic permeability of approximately 2,000.

With the high permeability core of this invention, when the secondary winding circuit is approaching an open-circuit condition as occurs when the electrode-tissue interface is small the impedance of the primary winding is large, reducing the current flow in the amplifier to a low level, thereby permitting use of a transistorized amplifier. With the tightly coupled primary and secondary windings of this invention, a decrease in impedance in the secondary winding circuit, which occurs when the electrode-tissue interface is large, is efficiently reflected back to the primary winding. This reflectance, in combination with a step-down in winding turns from the secondary winding to the primary winding, significantly decreases the impedance of the primary winding circuit, permitting large currents to flow in the primary winding, in turn enabling large current levels to be transformer coupled to the electrode for maintaining the desired current density over the larger electrode-tissue interface. Thus, the unique transformer coupling of this invention permits a transistorized amplifier to be used which is capable of supplying a high level of current when the electrode-tissue interface is large, but yet is not damaged by high circulating currents when the electrode-tissue interface is small and the required output current level low.

It has been a further objective of this invention to provide a fully transistorized signal generator for generating continuous high frequency signals which, when amplified by the amplifier and transformer coupled to the surgical instrument, are effective

tive for cutting, and which also generates low frequency trains of high frequency signals which, when amplified by the amplifier and transformer coupled to the electro-surgical instrument, facilitate coagulation. This objective has been accomplished in accordance with certain additional principles of this invention by combining a high frequency oscillator connected to the amplifier input with a selectively operable low frequency oscillator in such a manner that when the low frequency oscillator is operative the output of the high frequency oscillator is selectively modulated, providing to the amplifier low frequency trains of high frequency signals which are useful for coagulation. When the low frequency oscillator is not operative, the output of the high frequency oscillator is not so modulated, providing to the amplifier a continuous stream of high frequency signals useful for cutting.

These and other objectives and advantages of the invention will become more readily apparent from a detailed description of a preferred embodiment taken in conjunction with the drawings in which,

FIG. 1 is a schematic circuit diagram of a preferred embodiment of the electro-surgical apparatus of this invention.

FIG. 2 is a detailed circuit diagram of the preferred embodiment.

FIG. 3 is a vertical cross-sectional view through the center of a preferred type of transformer useful in coupling the output of the power amplifier to the electro-conductive surgical instrument.

FIGS. 4a-4i are graphical representations of the signal waveforms present at various points in the circuit of FIG. 2 when the circuit is operated in the coagulation mode.

FIGS. 5a-5g are graphical representations of the signal waveforms present at various points in the circuit of FIG. 2 when the circuit is operated in the cutting mode.

In accordance with a preferred embodiment depicted in FIG. 1 incorporating certain of the principles of this invention, an electro-surgical apparatus includes a utilization circuit 9 having an electrically conductive surgical instrument 10. The instrument 10 is adapted to be used for electro-section, or cutting, when energized with a first specified current level herein termed a "cutting current" and/or used for electro-coagulation when energized with a second specified current level herein termed a "coagulating current." The configuration or geometry of the conductive surgical instrument 10 may take a variety of conventional forms. For example, the instrument 10 may be in the form of a needle electrode, a straight blade electrode, a ball electrode, a loop electrode, or a coagulation electrode, the particular form depending upon the use contemplated for the conductive surgical instrument.

The electro-surgical apparatus of this invention also includes a high frequency source of electrical signals 12. The signal frequency of source 12 is sufficiently high to avoid muscular and/or nervous response in the subject, whether it be a human being or animal, when operated upon with the surgical instrument 10. Preferably the signals output from the signal generator 12 are in the form of selectively variable length trains of 500 kc spikes. Such trains are produced by the interaction of a pulse generator 14, a pulse train length controller 16, and a differentiating and clamping circuit 18 which are interconnected and operate in a manner to be described in detail hereafter.

The electro-surgical apparatus of this invention further includes an amplifier circuit 20 connected between the high frequency signal source 12 and the utilization circuit 9 containing the conductive surgical instrument 10. The amplifier circuit 20 preferably includes an intermediate class B amplifier 22 and a class B power amplifier 24, also to be described. The amplifier circuit 20 is further provided with a very unobvious transformer 27 for coupling power from the power amplifier 24 to the surgical instrument 10. The transformer 27 is characterized by having a core 30 which is fabricated of material having a magnetic permeability of approximately 2,000 and by having tightly coupled primary and secondary windings 26 and 28. This unique combination of core and

winding coupling reflects back to the primary winding 26, the load impedance of the secondary winding 28 and utilization circuit 9, enabling the power amplifier 24 to supply useful power to the surgical instrument 10 when the utilization circuit 9 is in a low impedance condition, as occurs when the electrode-tissue interface is large, without producing high current levels in the power amplifier when the utilization circuit is in a high load impedance condition as is the case when the electrode-tissue interface is small. With relatively low current existing in the power amplifier 24 when the surgical instrument-tissue interface is small, the power amplifier 24 need not be designed to dissipate large amounts of power and hence may be transistorized, appreciably reducing its cost.

The high frequency pulse generator 14 preferably is in the form of a square wave producing astable oscillator or multivibrator 39 having a pair of cross-coupled NPN-transistors 40 and 41. The emitters of transistors 40 and 41 are connected in common to ground potential 42 via a switch 43 and a line 38. The collectors of transistors 40 and 41 are connected via current limiting resistors 44 and 45, respectively, to a positive line 46 which constitutes the output of a signal train length controller 16. The bases of the transistors 40 and 41 are connected via capacitors 47 and 48 to the collectors of transistors 41 and 40, respectively, and to a balancing potentiometer 49 responsive to the input line 46 via resistors 51 and 52, respectively. The collectors of transistors 40 and 41 constitute complementary square wave outputs of the multivibrator 39 and are connected via output lines 53 and 54, to the differentiating and clamping circuit 18 to be described. The values of the multivibrator 39 are selected such that the square wave frequency of the multivibrator 39 exceeds the muscular and/or nervous response frequency of the subject being operated upon by the conductive surgical instrument 10. Preferably the multivibrator 39 has an operating frequency of 500 kc or higher.

The signal train length controller 16 includes a low frequency oscillator 60, preferably a pulse wave producing astable multivibrator, which controls a transistor switch 61 interconnected between a source of positive potential 62 and the input line 46 of the high frequency signal generator 14. The multivibrator 60 includes a pair of cross-coupled transistors 64 and 65, the emitters of which are connected to the selectively grounded line 38. The bases of the transistor 64 and 65 are coupled via capacitors 66 and 67 to the collectors of transistor 65 and 64, respectively, and to a positive line 72 via variable resistors 68 and 69. Positive line 72 is connected to the positive source 62 via a bistable movable contact 75. Current limiting resistors 70 and 71 interconnect the collectors of transistors 64 and 65 with the positive line 72. Variable resistors 68 and 69 function to permit the on-off intervals of transistors 64 and 65 to be varied. The output of the multivibrator 60, which is taken at the collector of transistor 65, alternates between high and low potential levels as the transistor 65 alternately switches between nonconductive and conductive states, respectively. The duration of the interval of relatively high output signal level, that is, the pulse width at the collector of transistor 65 relative to the duration of the interval of low output signal level, that is, the pulse spacing can be varied between approximately 3:1 and 1:3 by altering the resistance of the variable resistors 68 and 69. The circuit parameters of multivibrator 60 are preferably selected to provide a frequency of 50-80 kc.

The transistor switch 61 has its collector connected via the movable bistable contact 75 to the source of positive potential 62, and its emitter connected to the input line 46 of the high frequency multivibrator 39. The base of the transistor switch 61 is connected via a capacitor 73 to the output of the low frequency multivibrator 60 output taken at the collector of transistor 65. The capacitor 73 functions to damp the amplitude of the trailing edge portion of the pulses input to the base of transistor 61 from the output of the multivibrator 60 taken at the collector of transistor 65, for reasons to become evident hereafter.

In operation, with the movable contact 75 in the position shown and the switch 43 closed, positive potential from the source 62 is connected to the positive multivibrator line 72, as well as to the collector of the transistor switch 61. With positive potential from the source 62 coupled to the multivibrator 60, the multivibrator produces a continuous stream of pulses 60A (FIG. 4a) at its output taken at the collector of transistor 65. The width 60W of the pulses 60A as well as the spacing 60S between pulses depends upon the setting of the variable resistors 68 and 69. The stream of pulses 60A output from the multivibrator 60 at the collector of transistor 65 are input via the damping capacitor 73 to the base of the transistor switch 61, alternately switching the transistor switch 61 between conductive and non-conductive states in synchronism with the pulses 60A and spaces 60S, respectively, in turn producing a stream of pulses 46A (FIG. 4b) on line 46. The length 46W of the pulses 46A established by the conductive interval of transistor 61 is less than the length 46S of the spaces between pulses 46A established by the nonconductive interval of transistor 65. This is due to the existence of the capacitor 73 which causes the transistor 61 to turn-off prior to the end of the pulse 60A output from the collector of transistor 65. The shape of pulses 46A on line 46 is characterized by a damped amplitude due to the fact that capacitor 73, as it approaches a fully charged condition, effects a gradual turn-off of the transistor 61.

While the transistor 61 is in its conductive state potential from the source 62 is applied in the form of pulses 46A to the multivibrator 39 via line 46, enabling the low frequency complementary pulse train outputs 53A and 54A (FIG. 4c and 4f) of high frequency pulses to be generated on output lines 53 and 54. The amplitude of the high frequency pulses of trains 53A and 54A output from multivibrator 39 on lines 53 and 54 remains at a maximum level until the transistor switch 61 starts to turn-off as the capacitor 73 reaches a charged level toward the end of the positive pulses 46A at which time the amplitude of the pulses of trains 53A and 54A on lines 53 and 54 begins to decrease, eventually falling to zero when transistor 61 switches. Thus, for a small fraction of the duration of the positive pulses 46A output at the emitter of transistor 61 on line 46 when the transistor switch 61 is switching the amplitude of the high frequency pulses of trains 53A and 54A output on lines 53 and 54 gradually decreases from its maximum level, giving the slightly damped characteristic to the trains of high frequency pulses 53A and 54A on lines 53 and 54.

Summarizing, with the switch 75 in the position shown, a single damped amplitude train of high frequency complementary pulses 53A and 54A are output on each of lines 53 and 54 from the multivibrator 39 for each pulse 60A output from the low frequency multivibrator 60. The length 53W and 54W of the pulse trains 53A and 54A is a function of the conductive interval 46W of the transistor 61, which in turn is a function of the nonconduction interval 60W of transistor 65, while the spacing 53S and 54S between the pulse trains 53A and 54A is a function of the nonconductive interval 46S of the transistor 61, which in turn is a function of the conductive interval 60S of the transistor 65.

Were the capacitor 73 to be removed and the output of the multivibrator 60 taken at the collector of transistor 65 directly coupled to the base of transistor 61, the transistor switch 61 would switch more abruptly, producing undamped pulses on line 46. This in turn would terminate the train of high frequency pulses on lines 53 and 54 abruptly and damping of the high frequency pulses in the pulse trains would not occur.

When movable switch contact 75 is in the position opposite to that shown in FIG. 2, positive source 62 is disconnected from multivibrator 60, de-energizing this multivibrator, and is connected to the multivibrator 39 continuously energizing this multivibrator. With multivibrator 39 continuously energized, continuous streams of high frequency pulses 53B and 54B (FIG. 5a and 5d) are output from the signal generator 14 on lines 53 and 54.

The differentiating and clamping circuit 18 includes a first differentiator 80, comprising a capacitor 81 and a potentiometer 82 which are series connected between the output line 54 of the multivibrator 39 and a line 83 which is selectively connected to ground 84 via a switch 85, and a second differentiator 86, comprising a capacitor 87 and a potentiometer 88 which are series connected between the output line 53 of the multivibrator 39 and the selectively groundable line 83. The tap points 90 and 91 of the potentiometers 80 and 86 constitute the outputs of the differentiators 80 and 86. Diodes 92 and 93 connected between differentiator outputs 90 and 91, respectively, and the selectively groundable line 83 function to bypass to ground line 83 negative differentiated spikes output at the differentiator outputs 90 and 91, thereby effectively clamping the differentiator outputs 90 and 91 at ground potential. When the output on lines 53 and 54 take the form of low frequency trains of high frequency pulses 53A and 54A, as occurs when contact 75 is in the position shown in FIG. 2, the output of the differentiators 86 and 80 on lines 91 and 90 takes the form of low frequency trains of high frequency positive spikes 91A and 90A (FIG. 4d, 4g). When the output on lines 53 and 54 takes the form of continuous streams of high frequency pulses 53B and 54B (FIG. 5d, 5a), as is the case when movable contact 75 is in the position opposite to that shown in FIG. 2, the output of differentiators 86 and 80 on lines 91 and 90 takes the form of continuous streams of high frequency positive spikes 91B and 90B (FIG. 5b, 5e).

The intermediate class B amplifier 22 includes a pair of NPN-transistors 95 and 96, the emitters of which are connected in common to the selectively groundable line 83. The collectors of transistors 95 and 96 are connected to opposite ends of a primary winding 97 of a transformer 94. Primary winding 97 has a center tap 98 dividing the winding into sections 97A and 97B which is connected to a source of positive potential 99 and to ground potential 100 via a commutating capacitor 101. Diodes 102 and 103 are connected in parallel with the emitter-collector paths of transistors 95 and 96, respectively, and function to complete circuits between the commutating capacitor 101 and the winding sections 97A and 97B, respectively, enabling the current of the collapsing fields of the primary winding sections 97A and 97B to be alternately stored in the commutating capacitor 101 when the transistors 95 and 96, respectively are alternately nonconducting.

In the absence of a positive signal spike input to the bases of transistors 95 and 96, such as spikes 91A or 91B and 90A or 90B output on lines 91 and 90, the transistors 95 and 96 are nonconductive due to their class B mode of operation. The transistors 95 and 96 are alternately rendered conductive by the alternate positive spikes, such as spikes 91A or 91B and 90A or 90B output from the differentiators and clamping circuits on lines 91 and 90. Since the outputs 53A or 53B and 54A or 54B on lines 53 and 54 from the multivibrator 39 are complementary, the positive voltage spikes 91A or 91B and 90A or 90B output from the differentiating and clamping circuits on lines 91 and 90 occur on an alternate basis, thereby alternately rendering conductive class B amplifying transistors 95 and 96. With the amplifiers 95 and 96 alternately conductive, outputs from the amplifier 22 are provided across the transformer primary winding sections 97A and 97B of a transformer 94 on an alternative basis. The waveform of the alternate outputs of transistors 95 and 96 present across primary winding sections 97A and 97B approximates the waveform of the alternate inputs to the transistors 95 and 96 on lines 91 and 90, such as waveforms 91A or 91B and 90A or 90B.

The class B power amplifier 24 includes a pair of NPN-transistors 110 and 111 whose emitters are connected in common to the selectively groundable line 83. The collectors of the transistors 110 and 111 are connected to opposite ends of the primary winding of transformer 27 having a center tap 113 which divides the primary winding into sections 26A and 26B. The center tap 113 is connected to a source of positive potential 114 and to ground potential 115 via a commutating capacitor 116. Diodes 108 and 109 are connected in shunt

with the emitter-collector paths of transistors 110 and 111, and function to complete circuits between the commutating capacitor 116 and the primary winding sections 26A and 26B to enable the current alternately generated by the alternately collapsing fields of winding sections 26A and 26B to be alternately stored in the capacitor.

The input to the class B transistor amplifiers 110 and 111 is provided by secondary winding sections 118A and 118B which collectively constitute a center-tapped secondary winding 118 of transformer 94. Preferably, center-tapped secondary winding 118 and center-tapped primary winding 97 are wound on a pair of cup cores 124 of the type marketed by Ferroxcube Corporation of America, Saugerties, New York, designated Model 3622P-LOO-3B7, having 9,660 mH per 1,000 turns. The waveform input to power transistor amplifiers 110 and 111 via secondary winding sections 118a and 118b approximate the waveform output from transistor amplifiers 95 and 96 across primary winding sections 97a and 97b. The output from the primary winding sections 97a and 97b of primary winding 97 is transformer coupled to secondary winding sections 118a and 118b of secondary winding 118 by sections 124A and 124B of transformer core 124.

The output of the class B transistor power amplifiers 110 and 111 is taken across the primary winding sections 26a and 26b of center-tapped primary winding 26 of the transformer 27, and approximates in waveform the input to the transistors on center-tapped secondary winding sections 118a and 118b. The output of the center-tapped transformer primary winding 26a is coupled to the electro-surgical instrument 10 of utilization circuit 9 via the secondary winding 28 of transformer 27 which is flux-linked to primary winding 26 by core 30.

When the electrode-tissue interface is small the load impedance of the amplifier 24 established by the impedance of the utilization circuit 9 and the secondary winding 28 of transformer 27 is very large, for example, approximately 1,000 ohms. To prevent damaging current levels from being produced in the power amplifier 24, which would rapidly damage the transistors 110 and 111, when the amplifier load impedance is in its high impedance condition, the core 30 of the transformer 27 is fabricated of material having an extremely high magnetic permeability. With the core 30 so fabricated, the impedance of the primary winding 26 of the transformer 27 is extremely high when the electrode-tissue interface is small; in turn causing the current through the emitter-collector paths of transistors 110 and 111 to be maintained at low levels, preventing damage to transistors 110 and 111.

When the electrode-tissue interface is large the load impedance of the amplifier 24 established by the utilization circuit 9 and the secondary winding 28 of the transformer 27 is relatively low, for example, approximately 100 ohms. To reflect back to the primary winding 26 of transformer 27 this low amplifier load impedance when the electrode-tissue interface is large, the secondary and primary windings 28 and 26 of the transformer 27 are tightly coupled. This permits large currents to flow through primary winding 26 and thereby supply useful power levels to the instrument 10, when the electrode-tissue interface is large and the load impedance of the amplifier 24 is in its low impedance condition.

To satisfy both the tight coupling requirement for transformer windings 26 and 28 and the need for high magnetic permeability for the core 30, windings 26 and 28 are preferably wound on a pair of cup cores of the type marketed by Ferroxcube Corporation of America, designated Model 4229P-LOO-3B7, having 10,300 mH per 1,000 turns. Such a winding-core combination, as best seen in FIG. 3, includes a hollow cylinder 30a having sealed ends 30b and 30c which are connected by a rod 30d about which are wound on a bobbin 30e the primary and secondary windings 26 and 28. In a preferred form, the primary winding 26 has seven turns and the secondary winding 28 has 40 turns, providing an open circuit voltage across the secondary winding of approximately 1,000 volts when connected in a power amplifier circuit 24 having the parameters shown.

By virtue of the high magnetic permeability of the core 30 and the tight coupling of the windings 26 and 28, the power amplifier 24 is able to provide large currents to the surgical instrument 10 to maintain the desired current density over the entire electrode-tissue interface when the interface is large without producing large currents in the amplifier when the electrode-tissue interface is small and lesser current levels are required to maintain the desired current density over the smaller area of the interface. With low current in amplifier 24 when the electrode-tissue interface is small, the amplifier can be transistorized without fear of damage.

In operation, if the instrument 10 is to be used for cutting, that is, if a cutting current is required, the movable contact 75 is placed in the position opposite that shown in FIG. 2. In such position the multivibrator 60 is de-energized and the multivibrator 39 continuously energized. With the multivibrator 39 continuously energized continuous streams of complementary pulses 53B and 54B (FIGS. 5d and 5a) are produced on lines 53 and 54 and input to the differentiating and clamping circuit 18. The continuous streams of complementary pulses 53B and 54B on lines 53 and 54, after differentiation and clamping, provide on lines 91 and 90 to the bases of transistors 95 and 96 continuous streams of positive voltage spike 91B and 90B (FIGS. 5e and 5b) which are interleaved in time, causing the transistors 95 and 96 to alternately conduct. The alternate conduction of transistors 95 and 96 produces continuous streams of interleaved signals across primary windings 97a and 97b which are transformer coupled to transistors 110 and 111 via secondary windings 118a and 118b, in turn causing these latter transistors to alternately conduct. The alternate conduction of transistors 110 and 111 produces continuous streams of time-interleaved signals across primary winding sections 26a and 26b, which are transformer coupled to the surgical instrument 10 and combined via secondary winding 28, producing a single continuous stream of alternating current signals 28S as shown in FIG. 5g. The streams of signals present across transformer windings 97a, 118a, and 26a approximate each other in waveform, and accordingly are shown as a single waveform in FIG. 5f. b, The streams of signals present across transformer windings 97b, 118b, and 26b approximate each other in waveform, and are likewise shown in FIG. 5d as a single waveform.

If a coagulation current is to be supplied to the surgical instrument 10, the movable contact 75 is placed in the solid line position shown in FIG. 2. With the movable contact 75 so positioned the multivibrator 60 is energized, providing a continuous stream of low frequency positive pulses 60A (FIG. 4a) to the base of the transistor switch 61. In response to this stream of positive pulses 60A, the transistor 61 is alternately rendered conductive (waveform 46A OF FIG. 4b) and non-conductive (waveform 46S OF FIG. 4b) at a frequency equal to the frequency of the multivibrator 60. When the transistor 61 is conductive, which corresponds to once per pulse 60A (FIG. 4a) output from the multivibrator 60, trains of high frequency complimentary pulses 53A and 54A (FIGS. 4f and 4c) are provided on output lines 53 and 54 from the multivibrator 39. The trains of complimentary pulses 53A and 54A on lines 53 and 54 are differentiated and clamped, producing on lines 91 and 90, trains of time-interleaved spikes 91A and 90A (FIGS. 4g and 4d) which alternately render transistors 95 and 96 conductive, producing time interleaved trains of signals across primary winding sections 97a and 97b which are input to transistors 110 and 111 via transformer coupled secondary winding sections 118a and 118b. The time-interleaved inputs to transistors 110 and 111 cause these transistors to alternately conduct, producing time-interleaved trains of signals across transformer primary winding sections 26a and 26b which are coupled to the surgical instrument 10 and combined via the secondary winding 28, producing trains of alternating current signals 28T shown in FIG. 4i. The trains of signals across transformer windings 97a, 118a, and 26a approximate each other in waveform and hence are shown as a single waveform in FIG. 4h. The trains of signals across transformers windings 97b, 118b, and 26b also approximate each other in waveform and hence are also shown as a single waveform in FIG. 4e.

At this juncture it should be understood that both the length of the pulse trains 28T (FIG. 4i) and the spacing between trains can be varied by varying the pulse width 60W and spacing 60S of the pulses 60A (FIG. 4a). Such pulse width and spacing variations are accomplished by altering the resistance of resistors 68 and 69 (FIG. 2) which vary the on and off intervals of transistors 64 and 65 of the low frequency multivibrator 60.

In both the coagulation mode and the cutting mode the surgical instrument 10 is energized in substantially the same manner, the only difference between the modes of operation being that the surgical instrument 10 in the cutting mode is energized by a continuous stream of high frequency signals 28S (FIG. 5g), whereas in the coagulation mode the instrument 10 is energized by a sequence of low frequency trains of damped high frequency signals 28T (FIG. 4i).

I claim:

1. Electro-surgical apparatus comprising:

a utilization circuit including a conductive surgical instrument, said utilization circuit being susceptible of alternatively constituting relatively low and high impedance electrical loads as the area of the interface between said instrument and tissue varies between large and small values under differing conditions of use,

a source of high frequency electrical signals,

a transistorized power amplifier having an input circuit responsive to said high frequency electrical signals and an output circuit, and

a transformer having a core, a secondary winding wound on said core and connected to said utilization circuit, and a primary winding wound on said core and responsive to said output circuit of said transistorized amplifier, said transformer being a step-up transformer in which the number of turns of the secondary winding substantially exceeds the number of turns of the primary winding, said transformer being characterized by having said windings tightly coupled and by having said core fabricated of high magnetic permeability material for reflecting back to said primary winding the impedance of said secondary winding and utilization circuit, thereby enabling said transistor amplifier to supply useful current to said instrument when said utilization circuit is in its low load impedance condition without producing damaging currents in said amplifier when said utilization circuit is in its high load impedance condition.

2. The apparatus of claim 1 wherein the magnetic permeability of said core is approximately 2,000 and wherein said core is configured in the form of a hollow cylinder having closed ends internally connected by a rod about which said primary and secondary windings are wound.

3. The apparatus of claim 2 wherein said high frequency signal source includes a transistorized high frequency pulse generator and a differentiating circuit for converting output

pulses from said generator to signals having a high ratio of peak current to average current.

4. The apparatus of claim 3 further including:

a transistor switch connected between said pulse generator and a source of supply potential, and

a low frequency oscillator having an output circuit connected to control said transistor switch for alternately de-energizing and energizing said pulse generator to enable successive trains of high frequency pulses to be input to said differentiating circuit during successive oscillations of said low frequency oscillator, thereby facilitating the application of a coagulating current level to said instrument.

5. The apparatus of claim 4 further including selectively operable switch means shunting said transistor switch for selectively continuously energizing said pulse generator, thereby facilitating the application of a cutting current level to said instrument.

6. The apparatus of claim 4 further including a capacitor interconnecting said low frequency oscillator and said transistor switch for damping the high frequency pulses of said trains.

7. Electro-surgical apparatus comprising:

a utilization circuit including a conductive surgical instrument, said utilization circuit being susceptible of alternatively constituting relatively low and high impedance electrical loads as the area of the interface between said instrument and tissue varies between large and small values under differing conditions of use,

a source of high frequency electrical signals,

a source of signal trains including a high frequency oscillator and a low frequency oscillator connected to provide low frequency trains of high frequency signals,

a power amplifier having an input circuit responsive to said signal trains and an output circuit, and

a transformer having a core, a secondary winding wound on said core and connected to said utilization circuit, and a primary winding wound on said core and responsive to said output circuit of said amplifier, said transformer being a step-up transformer in which the number of turns of the secondary winding substantially exceeds the number of turns of the primary winding, said transformer being characterized by having said windings tightly coupled and having a core fabricated of material having a magnetic permeability of approximately 2,000 and configured in the form of a hollow cylinder having closed ends connected by a rod about which said windings are wound, thereby reflecting back to said primary winding the load impedance of said secondary winding and utilization circuit to enable said amplifier to supply useful current to said instrument when said utilization circuit is in its low load impedance condition without producing damaging currents in said amplifier when said utilization circuit is in its high load impedance condition.

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