Feb. 24, 1948. M. NATHANSON 2,436,399.

FLUORESCENT TUBE LIGHTING SYSTEM

Filed Aug. 24, 1946 9 Sheets-Sheet 1

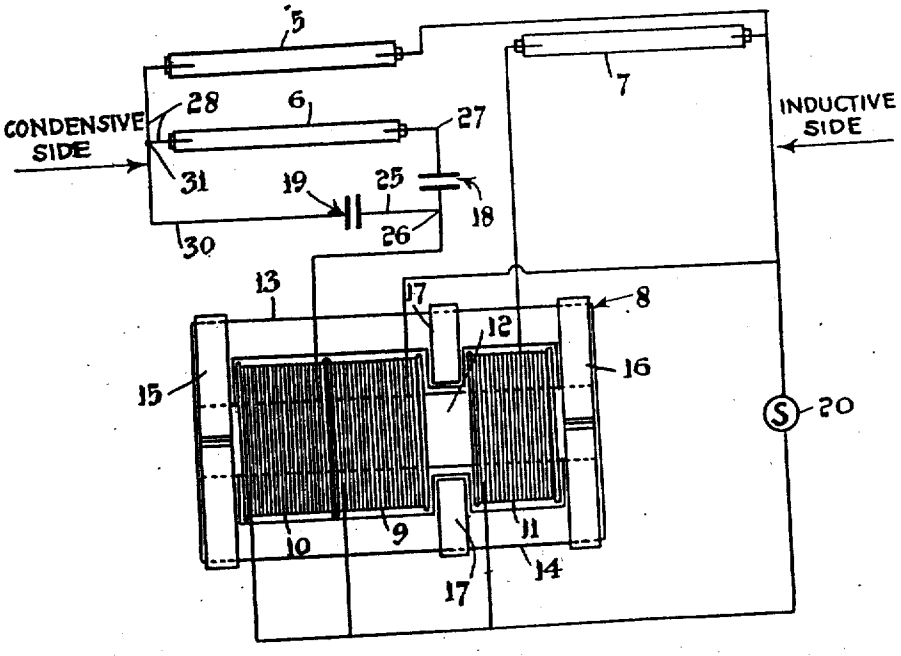


FIG. 1

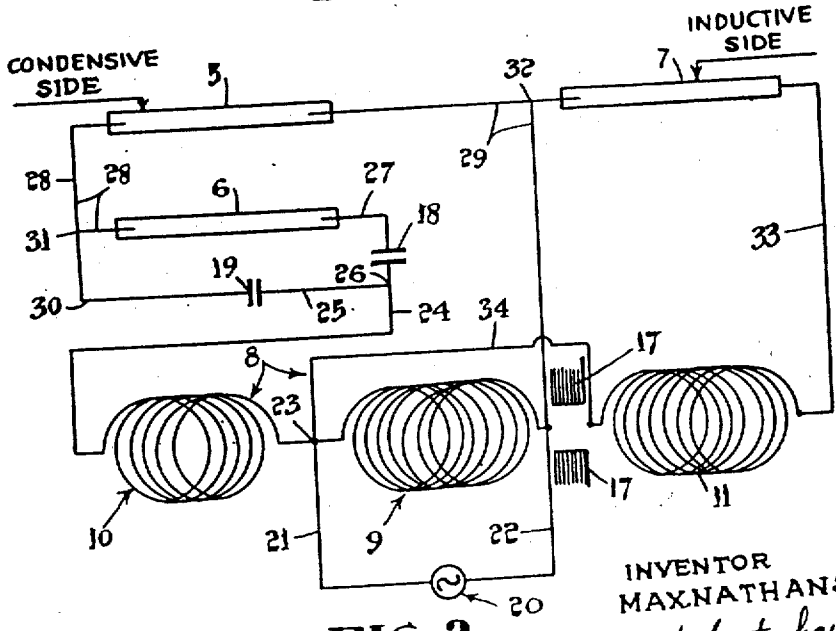


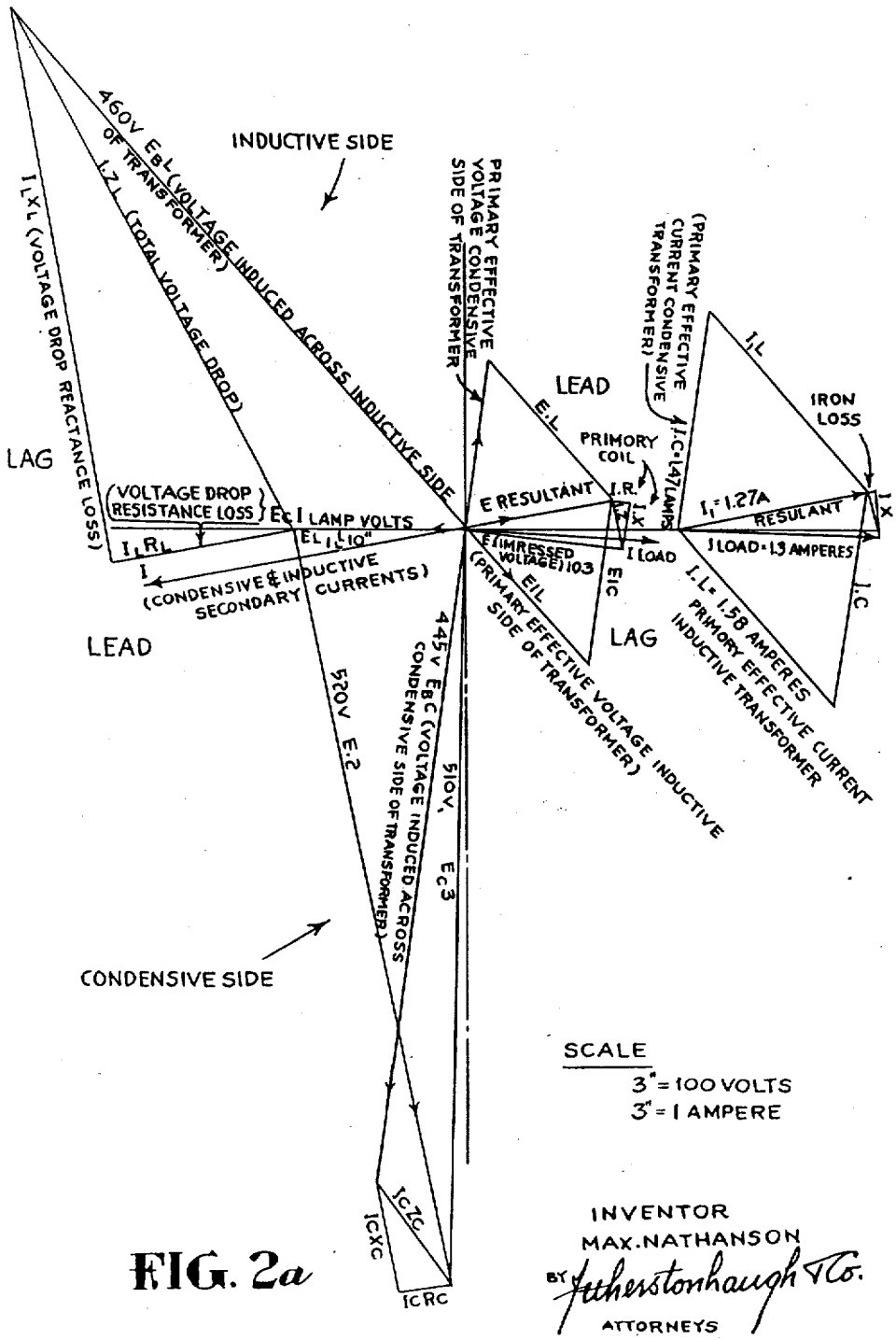
FIG. 2

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FLUORESCENT TUBE LIGHTING SYSTEM

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SCALE

3" = 100 VOLTS

3" = 1 AMPERE

FIG. 2a

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Feb. 24, 1948. M. NATHANSON 2,436,399

FLUORESCENT TUBE LIGHTING SYSTEM

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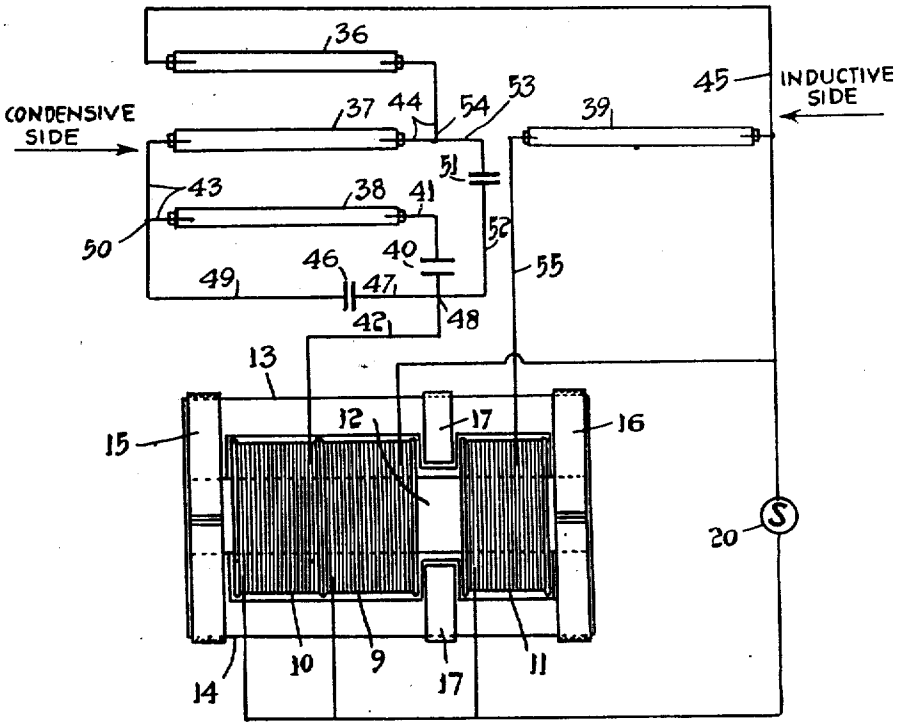


FIG. 3

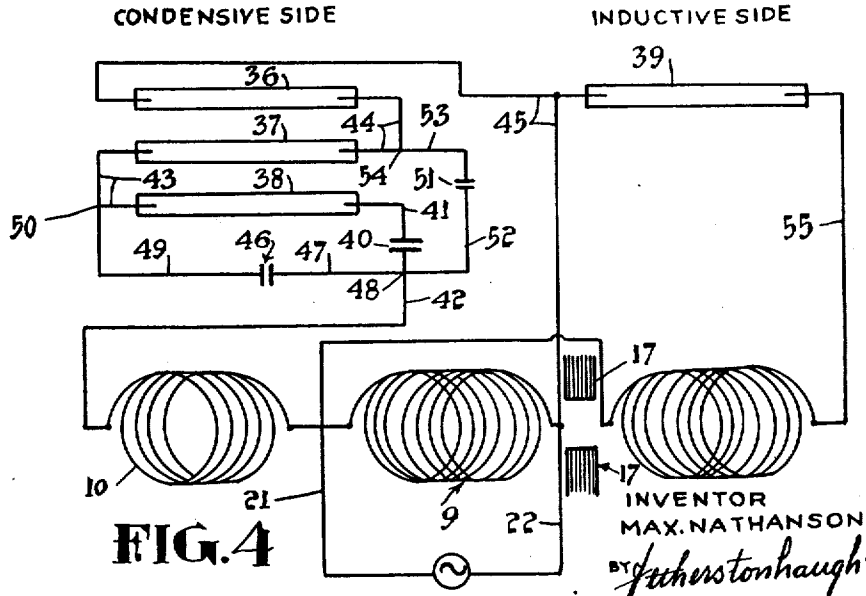


FIG. 4

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FLUORESCENT TUBE LIGHTING SYSTEM

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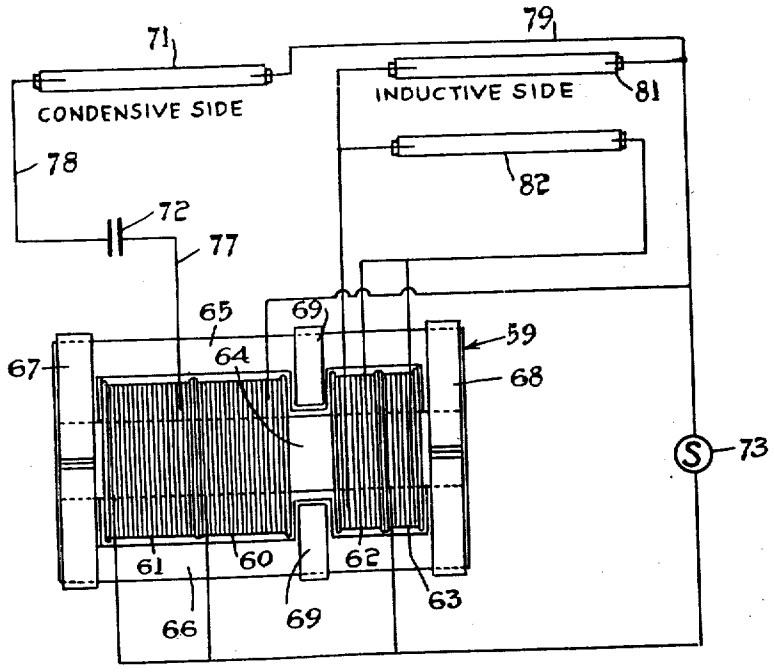


FIG. 5

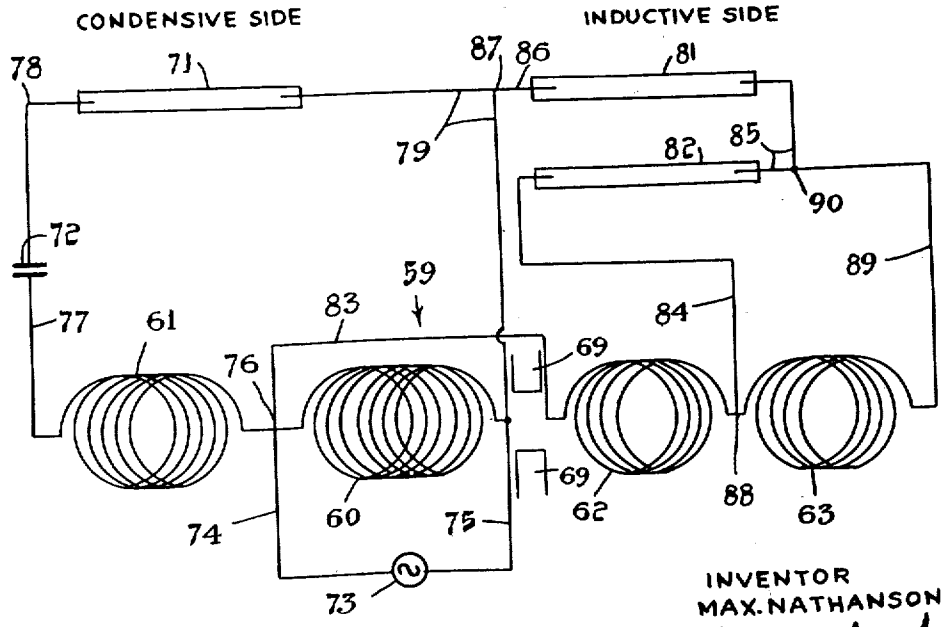


FIG. 6

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FLUORESCENT TUBE LIGHTING SYSTEM

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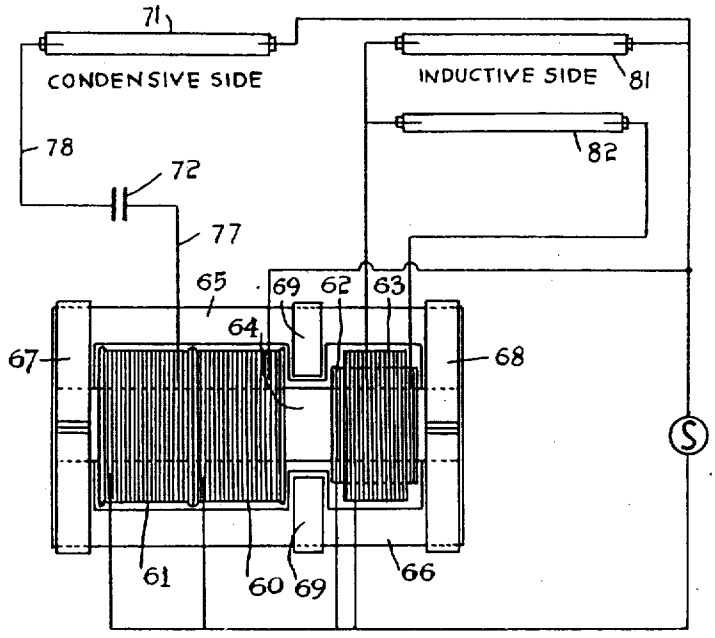


FIG. 7

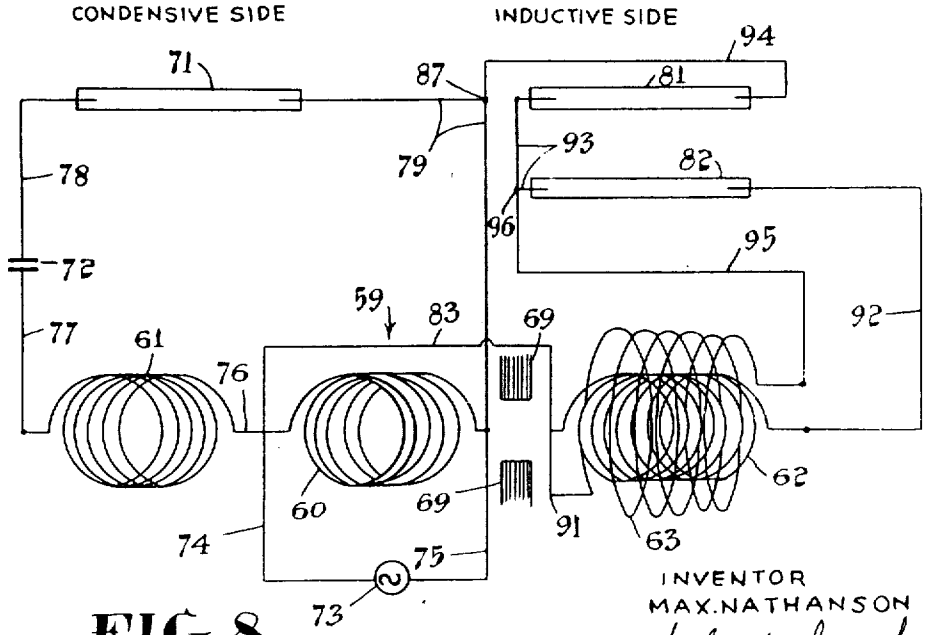


FIG. 8

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FLUORESCENT TUBE LIGHTING SYSTEM

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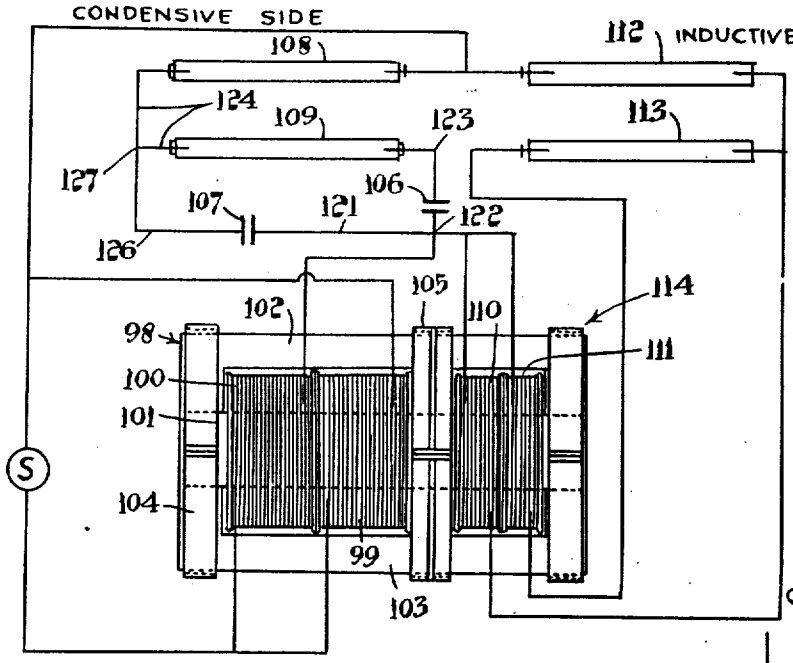


FIG.9

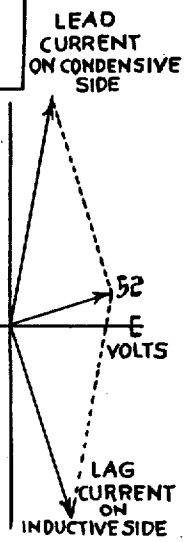


FIG.9a

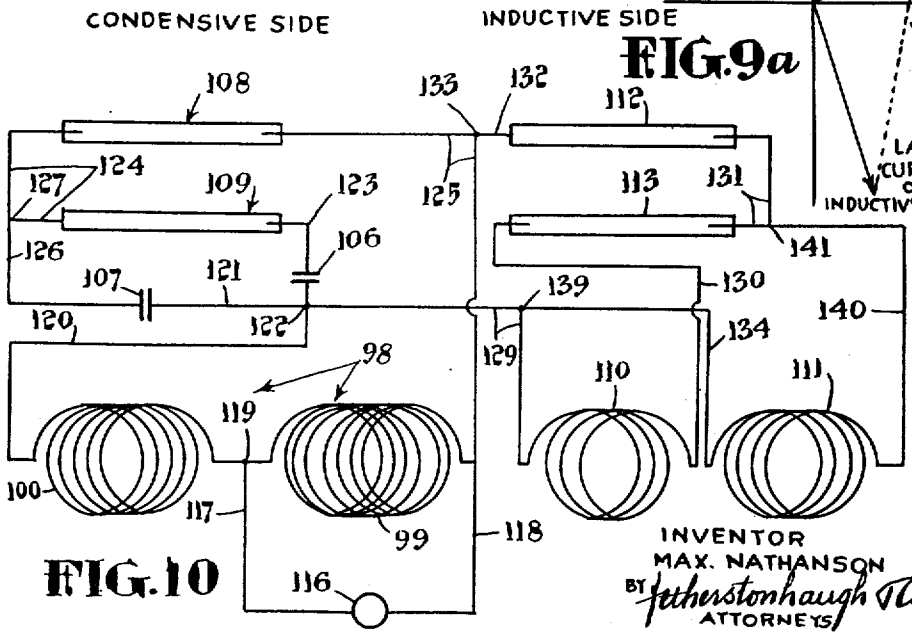


FIG.10

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FLUORESCENT TUBE LIGHTING SYSTEM

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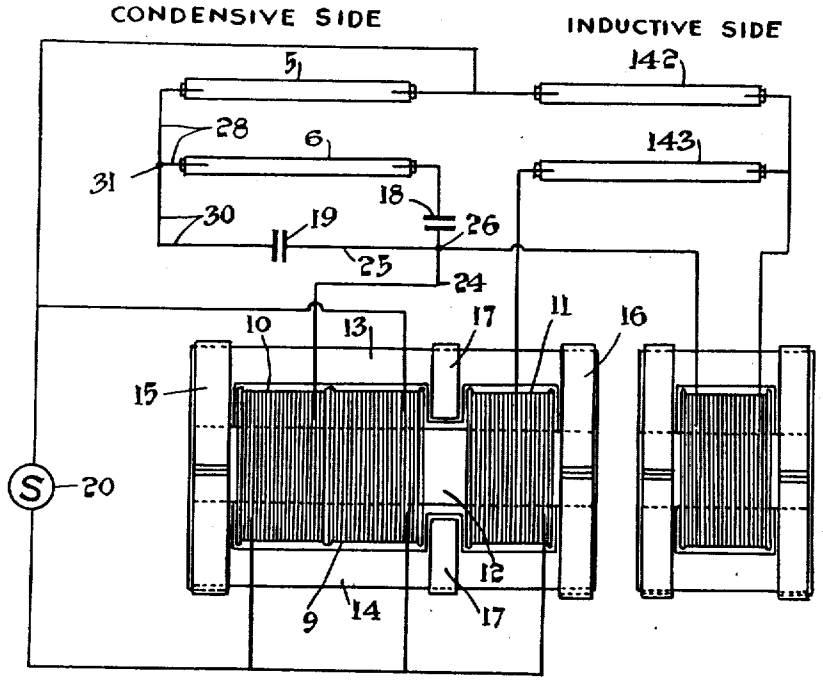


FIG. 11

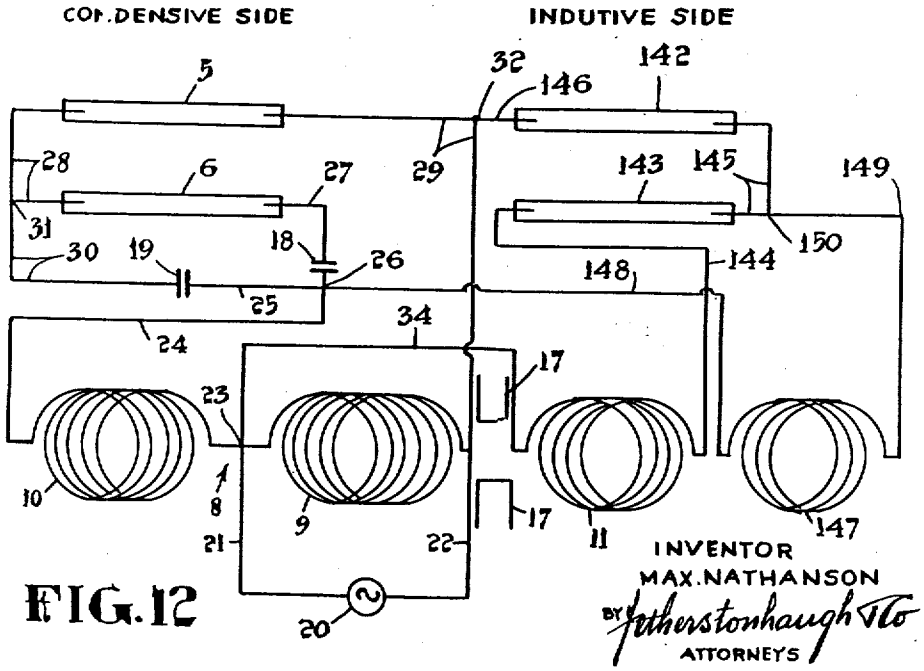


FIG. 12

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FLUORESCENT TUBE LIGHTING SYSTEM

Filed Aug. 24, 1946 9 Sheets-Sheet 8

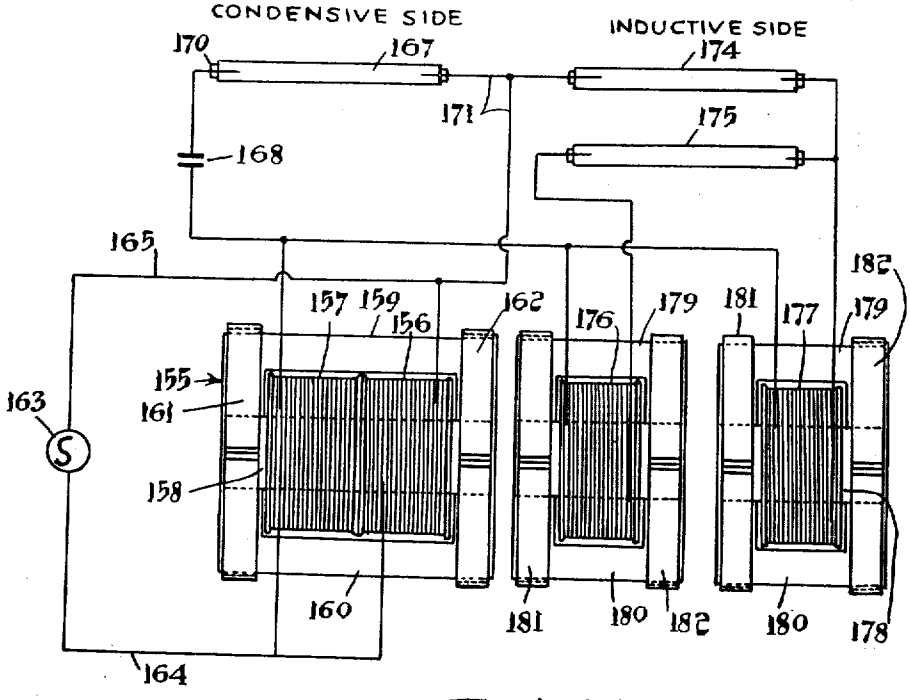


FIG. 13

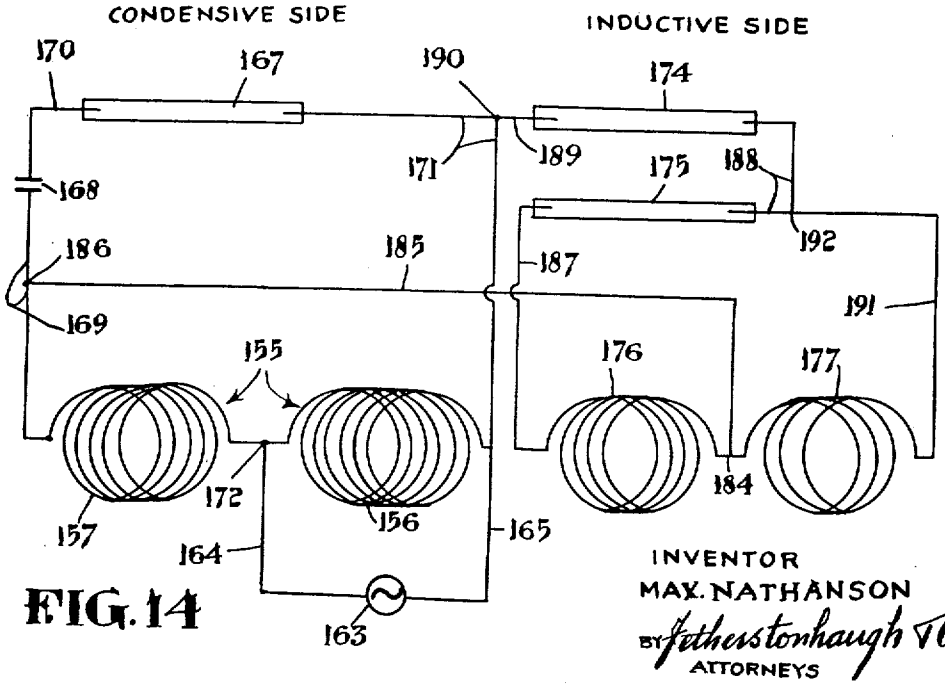


FIG. 14

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FLUORESCENT TUBE LIGHTING SYSTEM

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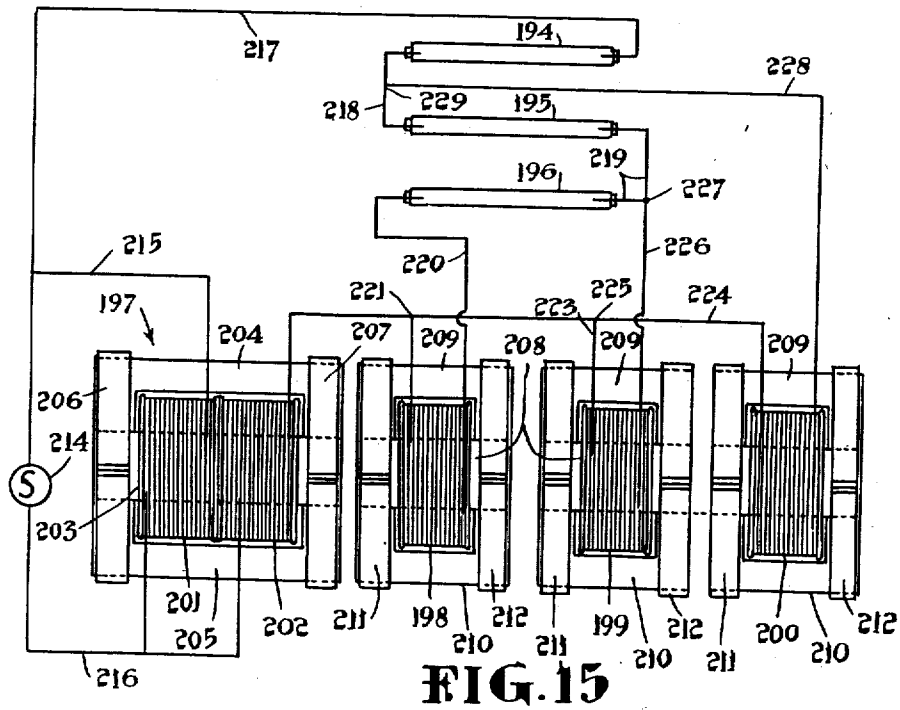


FIG. 15

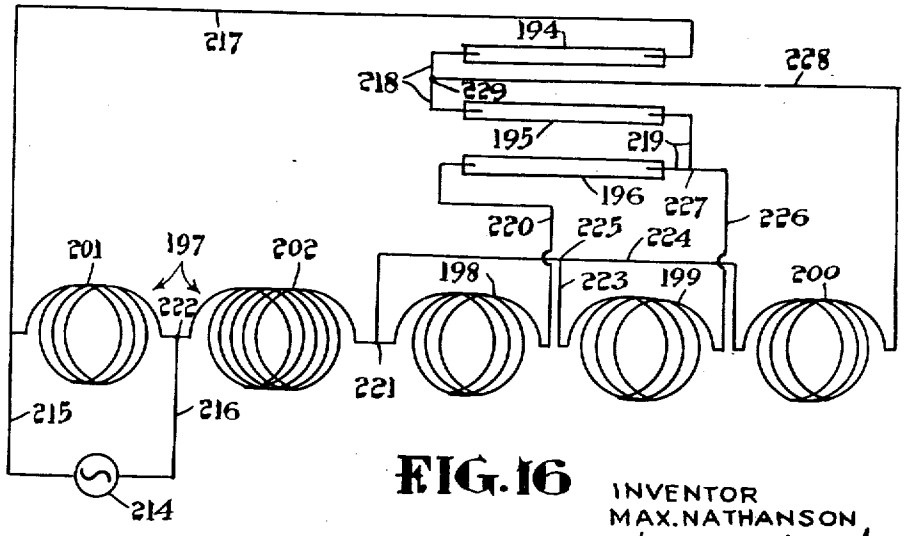


FIG. 16

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Patented Feb. 24, 1948 2,436,399

UNITED STATES PATENT OFFICE

2,436,399

FLUORESCENT TUBE LIGHTING SYSTEM

Max Nathanson, Montreal, Quebec, Canada

Application August 24, 1946, Serial No. 692,906

7 Claims. (Cl. 315—323)

1

My invention relates to improvements in fluorescent tube lighting systems and is particularly useful in connection with the design and operation of domestic and other relatively low-voltage fluorescent tube lighting systems in which the use of operating voltages substantially higher than 500–600 volts is undesirable or prohibited by existing regulations. In such relatively low-voltage systems, the tubes are operated in parallel with each other since the voltage required to operate two or more tubes connected in series across the source of current by a simple series connection would be prohibitively high.

My invention is based on the theory that important economies and other advantages can be achieved in the design and operation of fluorescent tube lighting systems, particularly the relatively low voltage systems previously referred to, if it were possible to operate two or more of the tubes in series at a voltage substantially lower than the voltage ordinarily required for operating two or more tubes connected in series with each other across the source of current by the conventional simple series connection.

In dealing with this problem of obtaining theoretically possible economic and other advantages by operating fluorescent tubes in series at voltages which are substantially lower than ordinarily required and are preferably within the permissible range prescribed for operation of the previously mentioned relatively low-voltage systems, I have found a simple but far from obvious solution. More particularly I have found that this problem can be solved in a thoroughly practical and satisfactory manner by connecting a plurality of fluorescent tubes in series with each other across a source of alternating current and providing current-limiting by-pass means through which current is by-passed around one of the series connected tubes to establish an ionized and conductive condition of the remaining series connected tubes and thereby enable all of said tubes to be operated in series with each other at a voltage substantially lower than would be required in the absence of said by-pass means. This is the essence of my invention and may be applied to the operation of any desired number of fluorescent tubes connected in series with each other across a source of alternating current energy having an output voltage rating substantially lower than would be adequate to operate said tubes in the absence of said current limiting by-pass means.

In the operation of a fluorescent tube system embodying my invention it is important that

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the amount of current by-passed around one of the series connected tubes to initially establish an ionized and conductive condition of the remaining series connected tube or tubes be limited to the minimum required to establish and maintain ionization of the series connected tubes to which the by-passed current is supplied. In the ionized and conductive condition of the series connected tubes to which the by-passed current is supplied, the potential across the source of alternating current energy is immediately effective to establish an ionized and conductive condition of the remaining tubes and to cause sufficient operating current to flow in series through all of said tubes to maintain the current density required for satisfactory operation. In this connection it may be noted that suitable current limiting means is included in series with all of said tubes to limit the ultimate operating current in said tubes.

Proceeding now to more detailed discussion of my invention reference will be had to the accompanying drawings, in which—

Fig. 1 is a diagrammatic elevational view of a transformer and other component elements of a fluorescent lighting system embodying my invention.

Fig. 2 is a wiring diagram of the system shown in Fig. 1.

Fig. 2a is a vector diagram applicable to the system shown in Figs. 1 and 2.

Fig. 3 is a view similar to Fig. 1 but illustrating a modification of the invention.

Fig. 4 is a wiring diagram of the modified system shown in Fig. 3.

Fig. 5 is a view similar to Fig. 1 but showing a further modification.

Fig. 6 is a wiring diagram of the modified system shown in Fig. 5.

Fig. 7 is a view similar to Fig. 1 but showing a further modification.

Fig. 8 is a wiring diagram of the system shown in Fig. 7.

Fig. 9 is a view similar to Fig. 1 but showing a still further modification.

Fig. 9a is a vector diagram applicable to the system shown in Fig. 9.

Fig. 10 is a wiring diagram of the system shown in Fig. 9.

Fig. 11 is a view similar to Fig. 1 but showing a still further modification.

Fig. 12 is a wiring diagram of the system shown in Fig. 11.

Fig. 13 is a view similar to Fig. 1 but showing a still further modification.

Fig. 14 is a wiring diagram of the system shown in Fig. 13.

Fig. 15 is a view similar to Fig. 1 but showing a still further modification.

Fig. 16 is a wiring diagram of the system shown in Fig. 15.

The system shown in Figures 1 and 2 comprises three fluorescent tubes 5, 6 and 7, operated by a single transformer 8, including a primary coil 9 and two secondary coils 10 and 11.

Transformer 8 is here shown as a high leakage reactance shell-type auto-transformer having a central core leg 12 on which the three transformer coils are arranged in side by side relation with primary coil 9 lying between secondary coils 10 and 11. The central leg 12 lies between outer legs 13 and 14 in spaced parallel relation therewith and all of said legs are joined to end pieces 15 and 16. Primary coil 9 and secondary coil 11 lie at opposite sides of high leakage reactance magnetic shunts 17.

Tubes 5 and 6 are connected in series with each other across transformer coils 9 and 10 while tube 7 is connected across transformer coils 9 and 11. Two current-limiting condensers, 18 and 19, are suitably included in the circuit connections of lamps 5 and 6 to enable these lamps to be successfully operated in series at voltages within the permissible maximum limits prescribed for safe operation of fluorescent-tube lighting equipment.

Primary coil 9 of transformer 8 is energized by a source of alternating-current energy 20 which may be of any suitable voltage and frequency rate. Voltages of the order of 110 or 220 volts and frequencies of the order of 25, 50, or 60 cycles are satisfactory for practical operation.

In tracing the circuit connections as shown in Fig. 2 it will be noted that primary coil 9 of transformer 8 is connected across the alternating current potential source 20 by leads 21 and 22. The left hand end of coil 9 is connected to the right hand end of coil 10 at junction 23. The left hand end of coil 10 is connected to the transformer side of condenser 18 by series-lead 24 and to the transformer side of condenser 19 by way of by-pass lead 25 which joins series lead 24 at junction 26. The tube side of condenser 18 is connected to the right hand electrode of tube 6 by lead 27. The left hand electrode of tube 6 is connected to the left hand electrode of tube 5 by lead 28. The right hand electrode of tube 5 is connected to the right hand end of coil 9 by lead 29. The tube side of condenser 19 is connected by lead 30 to lead 28 at junction 31. From this tracing of the circuit connections for tubes 5 and 6 and condensers 18 and 19, it will be apparent that condenser 19, with its connecting leads 25 and 30, provides a current-limiting by-pass through which current is shunted around tube 6 and through tube 5.

In tracing the circuit connections for tube 7 it will be noted that the left hand electrode of this tube is connected to lead 29 at junction 32 and that the right hand electrode is connected to the right hand end of coil 11 by lead 33. The left hand end of coil 11 is connected, by lead 34, to the left hand end of coil 9, at junction 23.

In the operation of the system shown in Figs. 1 and 2, the input potential impressed across primary coil 9 by the source 20 of alternating current energy is increased, by transformation, to a higher output potential across coils 9 and 10. This higher output potential is maintained within the maximum limits prescribed for safe operation and, in fact, corresponds to the potential (approximately 500 volts for a 40 watt tube) ordinarily employed for operating fluorescent tubes connected in parallel with each other.

The current-limiting condenser 19 and its connecting leads 25 and 30 afford a high-impedance by-pass through which a limited amount of current is shunted around tube 6 to initially establish an ionized or conductive condition of tube 5. The impedance of tube 5 is thus reduced to a value at which the voltage drop across said tube is extremely low in comparison with the voltage required to establish the ionized or conductive condition of the tube. In this connection, it will be understood that condenser 9 is designed so that its impedance is high enough to limit the flow of by-pass current in tube 5 to an amount of current which is just sufficient to establish and maintain the ionized or conductive condition of said tube. As will hereinafter be apparent this limitation of the amount of by-pass current supplied to tube 5 is necessary to keep the ultimate flow of operating current in this tube within proper limits.

In the ionized and conductive condition of tube 5, the potential across coils 9 and 10 is immediately effective to establish an ionized and conductive condition of tube 6 and to cause sufficient operating current to flow through the series connected condenser 18 and tubes 5 and 6 to establish and maintain in both of said tubes the current density required for satisfactory operation. In this connection, it will be understood that condenser 18 is designed to act as an impedance, limiting current flow in tubes 5 and 6, to the current limits for which the tubes are designed. For example, in the case of a 40 watt tube, the current limit is 430 milliamperes.

For further discussion of the operating characteristics of the system shown in Figs. 1 and 2, it will be assumed that transformer 8 is designed for 110 volts, 60 cycle operation and that the wattage rating of tubes 5 and 6 is 40 watts. In this case, the condenser 18 should have a high enough impedance to limit current flow therethrough to approximately 300 to 350 milliamperes. This amount of current will therefore flow through tube 6 in the ionized condition of the two series connected tubes but the amount of current flowing through tube 5 will be the vector sum of the current flowing through tube 6 and the amount of current flowing through the high impedance current-limiting by-pass condenser 19. For example, if the impedance of by-pass condenser 19 is high enough to limit current flow therethrough to 80 milliamperes, the current flow through tube 5 would be approximately 430 milliamperes which is the vector sum of the 350 milliampere flow through the main current-limiting condenser 18 and the 80 milliampere flow through the by-pass current-limiting condenser 19. Therefore, the average flow through tubes 5 and 6 will be approximately

$$350 \text{ ma.} + 430 \text{ ma.} = \frac{780 \text{ ma.}}{2} = 390 \text{ ma.}$$

The arrangement shown in Figures 1 and 2 is merely illustrative of one of numerous arrangements whereby a plurality of fluorescent tubes may be economically operated in series in accordance with the principles of my invention within permissible voltage limits and with a minimum increase in the size of the transformer. This illustration is applicable to a three tube 40 watt fixture with a total output of 120 watts on the tube side. In this connection, it may be noted

that, in the absence of tube 5 and condenser 19, approximately 400 milliamperes would be required to obtain a 40 watt output on the 40 watt tube 6. It will therefore be apparent that operation of the tubes 5 and 6 in series has not greatly altered the load on the transformer copper and that no appreciable alteration of coil 10 would be required in operating two or three tubes in series on the condensive side of the system. At this point, it may be explained that the term "condensive side of the system" is applied to that part of the system comprising tubes 5 and 6 and condensers 18 and 19 and their circuit connections as a convenient expedient for distinguishing this part of the system from the remaining part of the system which comprises tube 7 and its circuit connections and is hereinafter termed the inductive side of the system.

On the inductive side of the system the high potential impressed across tube 7 by coils 9 and 11 is sufficient to effect an ionized and conductive condition of said tube. Once current starts flowing in coil 11, the high reactance of this coil and the high reluctance of the magnetic shunts 17 are effective to limit the current flowing through tube 7 to the amount of current for which the tube is designed.

From the foregoing description it will be seen that on one side of the system (the inductive side) there is an inductive load created by the lamp 7 and the high inductive reactance coil 11 and that on the other side of the system (the condensive side) there is a condensive load created by the tubes 5 and 6, condensers 18 and 19 and coil 10. The vectorial summation of the inductive and condensive currents which are out of phase approximately 135° is illustrated by the vector diagram appearing in Fig. 2*a*. This diagram, with its applied legends, is self-explanatory, and clearly shows that the sum of current flowing in the primary winding 9 is extremely high power factor with resulting reduction of copper loss and transformer heating to an appropriate minimum. In this connection it may be observed that the manner in which condensers 18 and 19 are connected in circuit with tubes 5 and 6 makes it very easy to achieve a high power factor.

If the condensers 18 and 19 are combined into a single condenser unit with a tap brought out for making the common connection at junction 26, such a unit can be made available at a cost only slightly greater than the cost of the single condenser 19.

In designing a transformer and condenser assembly for use in the system shown in Figs. 1 and 2, the only additional expense involved would be the slight extra cost for the combined condenser unit and for the slightly heavier copper required in the primary coil 9. Actual tests have demonstrated that, in a system such as shown in Figs. 1 and 2, three tubes may be operated in series with the same amount of iron required for the operation of two tubes in series. It is therefore possible to provide a three-light instant start fixture embodying my invention at a cost approximately the same as the cost of a conventional three-tube hot-cathode fluorescent fixture using starters, or relays, or preheating elements in the tubes.

In connection with the foregoing discussion of Figs. 1 and 2 it will be apparent that, in the absence of the by-pass current-limiting condenser 19, approximately 1000 volts, (which is prohibited by safety regulations) would be required to operate the tubes 5 and 6 in series. By my method of including the condensers 18 and 19 (or other functionally equivalent current-limiting devices such as reactance or choke coils) in the circuit connections of the series connected tubes 5 and 6, it becomes possible to operate these tubes in series at a voltage of approximately 500 volts in a thoroughly practical and satisfactory manner. As previously stated, the small amount of current which condenser 19 allows to flow through lamp 5 at the available voltage of approximately 500 volts is sufficient to instantaneously establish an ionized and conductive condition of said lamp whereupon the high potential across coils 9 and 11 and condenser 18 becomes immediately effective to ionize tube 6 and to cause sufficient current to flow in series through both tubes, the impedance of condenser 18 being high enough to limit the currents in the series connected tubes to practical design limits.

The modified 4-tube system shown in Figs. 3 and 4 illustrates a feasible arrangement for operating three of the tubes in series on the condensive side of the system, the fourth tube being on the inductive side of the system and operated in the same manner as the previously operated tube 7.

In the arrangement shown in Figs. 3 and 4 the three tubes designated 36, 37, and 38 are connected in series with each other across transformer coils 9 and 10 and the fourth tube 39 is connected across transformer coils 9 and 11. In tracing the circuit connections shown in Fig. 4, it will be noted that a main current-limiting condenser 40, which serves the same purpose as the previously mentioned condenser 18, has its tube side connected to the right hand electrode of tube 38 by lead 41 and its transformer side connected to the left hand end of coil 10 by lead 42. The left hand electrode of tube 38 is connected to the left hand electrode of tube 37 by series-lead 43. The right hand electrode of tube 37 is connected to the right hand electrode of tube 36 by series-lead 44. The left hand electrode of tube 36 is connected to the right hand end of coil 9 by series lead 45. A current-limiting by-pass condenser 46, corresponding to the previously mentioned by-pass condenser 19, has its transformer side connected to the left hand end of coil 10 by lead 47 joining lead 42 at junction 48. The tube side of condenser 46 is connected to the left hand electrode of tube 37 by lead 49 joining lead 43 at junction 50. A second current-limiting by-pass condenser 51 similar to condenser 46 has its transformer side connected to the left hand end of coil 10 by lead 52 joining lead 42 at junction 48. The tube side of condenser 51 is connected to the right hand electrode of tube 35 by lead 53 joining lead 44 at junction 54.

In the system shown in Figs. 3 and 4, it is important that the transformer sides of the three condensers 40, 46 and 51 have the common point of connection represented by junction 48.

The operating characteristics of the system shown in Figs. 3 and 4 are substantially the same as described in connection with the system shown in Figs. 1 and 2. The by-pass current-limiting condensers 46 and 51 allow sufficient current to be by-passed around series-connected tube 38 to establish an ionized and conductive condition of the companion series-connected tubes 37 and 36, whereupon the voltage available across coils 9 and 10 becomes instantaneously effective to establish an ionized and conductive condition of series-

connected tube 38 and to cause flow of sufficient current through tubes 38, 37 and 36 in series to establish and maintain satisfactory operation of said tubes, the impedance of the main current-limiting condenser 40 being high enough to limit the operating current in the three series connected tubes to practical design limits.

In tracing the circuit connections for tube 39, it will be noted that this tube is connected across the coils 9 and 11 by conductors 45 and 55.

The 3-tube system shown in Figs. 5 and 6 illustrates a feasible arrangement wherein inductance coils are used to operate two of the tubes in series on the inductive side of the system.

The transformer generally indicated at 59 in Figs. 5 and 6 is shown as a high leakage reactance shell-type transformer comprising a primary coil 60 and three secondary coils 61, 62 and 63. The four coils are arranged in side by side relation on a central core leg 64 lying between and parallel with outer legs 65 and 66, all of said legs being joined to end pieces 67 and 68. Coils 60 and 61 are arranged on leg 64 at one side of high leakage reactance magnetic shunts 69. The remaining coils 62 and 63 are arranged on leg 64 at the opposite side of said shunts.

On what may be termed the condensive side of the system shown in Figs. 5 and 6 a fluorescent tube 71 is connected across coils 60 and 61 in series with a current-limiting condenser 72. In tracing the circuit connections of tube 71, as illustrated in Fig. 6, it will be noted that primary coil 60 is connected across an alternating current potential source 73 by leads 74 and 75. The left hand end of coil 60 is connected at junction 76 to the right hand end of coil 61. The left hand end of coil 61 is connected to the transformer side of condenser 72 by lead 77. The tube side of condenser 72 is connected to the left hand electrode of tube 71 by lead 78. The right hand electrode of tube 71 is connected to the right hand end of coil 60 by lead 79. The condenser 72 is charged by the high voltage secondary coil 61 and serves as a current-limiting device for the current which is supplied to tube 71 to establish an ionized, conductive, and luminescent condition of said tube.

On what may be termed the inductive side of the system shown in Figs. 5 and 6, a pair of fluorescent tubes 81 and 82 are connected in series with each other across the coils 60 and 62 by circuit connections which may be traced as follows:

The left hand end of coil 62 is connected by lead 83 to the left hand end of coil 60 at junction 76. The right hand end of coil 62 is connected by lead 84 to the left hand electrode of tube 82. The right hand electrode of tube 82 is connected to the right hand electrode of tube 81 by lead 85. The left hand electrode of tube 81 is connected to the right hand end of coil 60 by lead 86 joining lead 79 at junction 87.

The left hand end of coil 63 is connected to the right hand end of coil 62 at junction 88. The right hand end of coil 63 is connected to the right hand electrode of tube 81 by lead 89 joining lead 85 at junction 90.

From the foregoing description of the tube connections on the inductive side of the system shown in Figs. 5 and 6, it will be apparent that tubes 81 and 82 are connected in series across the coils 60 and 62 by way of series-leads 84, 85, 86 and 79. Coil 63 is a high impedance coil which, when connected as herein described, provides a high-impedance current-limiting by-pass

through which a limited amount of current is shunted around tube 82 to initially establish an ionized and conductive condition of tube 81. The impedance of tube 81 is thus reduced to a value at which the voltage drop across said tube is extremely low in comparison with the voltage initially required to establish an ionized and conductive condition of said tube. When an ionized and conductive condition is established in tube 81 by the small amount of ionizing current supplied to this tube by way of by-pass coil 63, the voltage available across coils 61 and 62 is immediately effective to establish an ionized and conductive condition of tube 82 and to cause sufficient current flow through the series connected tubes 82 and 81 to establish and maintain in both of said tubes the current density required for satisfactory operation. In this connection it may be explained that coil 62 is a high inductance coil which serves, in conjunction with the magnetic shunts 69, to limit the operating current in the series connected tubes 82 and 81 to practical design limits.

The system shown in Figs. 7 and 8 is similar to that shown in Figures 5 and 6 with the exception of a modification of the circuit connections of the coils 62 and 63 and the series connected tubes 81 and 82.

Referring more particularly to Fig. 8, it will be noted that the left hand end of coil 62 is connected, by lead 83, to the left hand end of coil 60 at junction 76 and that the left hand end of coil 63 is also connected to lead 83 at junction 91. The right hand end of coil 62 is connected to the right hand electrode of tube 82 by lead 92. The left hand electrode of tube 82 is connected to the left hand electrode of tube 81 by lead 93. The right hand electrode of tube 81 is connected to the right hand end of coil 60 by lead 94 which joins lead 79 at junction 87. The right hand end of coil 63 is connected to the left hand electrode of tube 81 by lead 95 which joins lead 93 at junction 96.

In the system shown in Figs. 7 and 8, a high voltage is impressed on tube 81 through coil 63 which is wound directly on coil 62 and sufficient bleeder current flows through coil 63 to establish an ionized and conductive condition of tube 81. When tube 81 is ignited, the reactance of coil 63 limits the current in said tube to a value just sufficient to maintain ionization and current flow. The resulting drop in the impedance of tube 81 enables the voltage generated in coil 62 to establish an ionized and conductive condition in tube 82 and to cause sufficient current flow through both of the series connected tubes 82 and 81 to establish and maintain in both of said tubes the current density required for satisfactory operation. The coils 62 and 63 shown in Figs. 7 and 8 are designed so that they are effective, in conjunction with shunts 69, to limit the operating current in tubes 82 and 81 to the proper value.

The four tube system shown in Figs. 9 and 10 illustrates an arrangement wherein a standard transformer is used in conjunction with current-limiting condensers to operate two tubes connected in series with each other on the condensive side of the system, the two remaining tubes being operated in series with each other on the inductive side of the system through the agency of suitably connected external reactance coils.

The transformer generally indicated at 98 in Figs. 9 and 10 is shown as a standard shell-type transformer comprising a primary coil 99 and a secondary coil 100 arranged in side by side rela-

tion on a central core leg 101 lying between and parallel with outer legs 102 and 103, all of said legs being joined to end pieces 104 and 105. As hereinafter described this transformer is used in conjunction with current-limiting condensers 106 and 107 to operate the tubes 108 and 109 in series with each other on the condensive side of the system. A pair of reactance coils 110 and 111 are designed and connected as hereinafter described to operate the tubes 112 and 113 in series with each other on the inductive side of the system.

The transformer unit 98 and the inductive coil unit 114 are completely separate and distinct units in the sense that they are not mechanically connected in any manner whatsoever, the inductive coil unit 114 being a complete unit with its coils 110 and 111 and laminations mechanically separate from the coils and laminations of the transformer unit.

In tracing the circuit connections of the system shown in Figs. 9 and 10 reference will be had particularly to Fig. 10 in which these connections are best shown. The primary coil 99 of transformer 98 is connected across any suitable source of alternating current energy 116 by leads 117 and 118. The left hand end of coil 99 is connected to the right hand end of coil 100 at junction 119. The left hand end of coil 100 is connected to the transformer side of the main current-limiting condenser 106 by lead 120. The left hand end of coil 100 is also connected to the transformer side of by-pass condenser 107 by lead 121 which joins lead 120 at junction 122. The tube side of condenser 106 is connected to the right hand electrode of tube 109 by lead 123. The left hand electrode of tube 109 is connected to the left hand electrode of tube 108 by lead 124. The right hand electrode of tube 108 is connected to the right hand end of coil 99 by lead 125. The tube side of condenser 107 is connected to the left hand electrode of tube 108 by conductor 126 which joins conductor 124 at junction 127. This completes the tracing of the circuit connections of the two tubes connected in series with each other on the condensive side of the system and it may be noted here that the condensers 106 and 107 correspond, respectively, to the condensers 18 and 19 shown in Figs. 1 and 2 and have substantially the same functional characteristics. The by-pass condenser 107 enables a small amount of current to be shunted around tube 109 to establish an ionized and conductive condition in tube 108 whereupon the voltage available across the coils 99 and 100 is immediately effective to establish an ionized and conductive condition of tube 109 and to effect the required flow of operating current through the tubes 109 and 108 in series.

In tracing the circuit connections on the inductive side of the system shown in Figs. 9 and 10, it will be noted that the left hand end of inductive coil 110 is connected by lead 129 to lead 120 at junction 122. The right hand end of coil 110 is connected by series-lead 130 to the left hand electrode of tube 113. The right hand electrode of tube 113 is connected to the right hand electrode of tube 112 by lead 131. The left hand electrode of tube 112 is connected by conductor 132 to lead 125 at junction 133. The left hand end of coil 111 is connected, by lead 134, to lead 129 at junction 139.

It will thus be seen that the left hand end of coil 111 is connected by leads 134 and 129 to lead 120 at junction 122, to which the transformer sides of condensers 106 and 107 are also commonly connected. The right hand end of coil 111 is connected to the right hand electrode of tube 112 by lead 140 which joins lead 131 at junction 141.

On the inductive side of the system shown in Figs. 9 and 10, the inductive coil 111 is an extremely high reactance coil which, with its connecting leads, affords a current-limiting by-pass through which a small amount of current is shunted around tube 113 to establish an ionized and conductive condition of tube 112. Once this condition of tube 112 is established, the voltage generated in coil 110 is effective to establish an ionized and conductive condition of tube 113 and to cause a limited amount of operating current, sufficient for satisfactory operation, to flow in series through tubes 113 and 112. In this connection, it may be explained that coil 110, when connected as herein described, functions as a limiting reactor or choke coil to maintain the proper operating current in tubes 113 and 112 in the ionized and conductive condition of said tubes.

In the system shown in Figs. 9 and 10 the currents on the condensive and inductive sides of the system are out of phase with the voltage, the current on the condensive side being approximately 90% leading and the current on the inductive side being approximately 90% lagging. The addition of these two current is diagrammatically illustrated in Fig. 9a which shows that the resultant current is lower than the currents flowing through each lamp circuit individually. The net result of this is that the current flowing in the transformer secondary coil 100 is very low as indicated on the vector diagram (Fig. 9a) by point 52 and the heating of the transformer is proportionately reduced.

The 4-tube system shown in Figs. 11 and 12 illustrates an arrangement wherein two of the tubes are operated in series with each other on the condensive side of the system in the manner described in connection with Figs. 1 and 2, the two remaining tubes being operated in series with each other on the inductive side of the system through the agency of a single external inductance or choke coil.

The condensive side of the system shown in Figs. 11 and 12 is the same as the condensive side of the system shown in Figs. 1 and 2 and the component elements, including the elements of the transformer, are correspondingly numbered.

On the inductive side of the system shown in Figs. 10 and 12, a pair of tubes 142 and 143 are operated in series with each other by means of suitable instrumentalities and circuit connections which will now be described with particular reference to Fig. 12.

The right hand end of the secondary transformer coil 11 is connected to the left hand electrode of tube 143 by series-lead 144. The right hand electrode of tube 143 is connected to the right hand electrode of tube 142 by series-lead 145. The left hand electrode of tube 142 is connected to the right hand end of transformer coil 9 by lead 146 which joins lead 29 at junction 32.

The left hand end of an external inductance or choke coil 147 is connected to junction 26 by lead 148. The right hand end of coil 147 is connected to the right hand electrode of tube 142 by lead 149 which joins lead 145 at junction 150.

The operation of tubes 5 and 6 in series with each other on the condensive side of the system shown in Figs. 11 and 12 is accomplished in the manner previously explained in connection with

the operation of the correspondingly numbered tubes on the condensive side of the system shown in Figs. 1 and 2.

On the inductive side of the system shown in Figs. 11 and 12, the external inductance or choke 147 and its connecting leads provide a current-limiting bypass through which a limited amount of current is shounted around tube 143 to establish an ionized and conductive condition of tube 142. At this point it may be noted that the potential across points 26 and 32 between which the tube 142 and coil 147 are connected in series with each other across coils 9 and 10 is high enough to effect ionization and current flow in tube 142, the amount of such current flow being restricted by coil 147 to the minimum required to establish and maintain ionization of tube 142. In the ionized condition of tube 142, the secondary transformer coil 11, acting as an auto-transformer in conjunction with primary coil 9, is effective in conjunction with shunts 17, to establish an ionized and conductive condition of tube 143 and to cause the proper amount of operating current to flow in both of the series-connected tubes 143 and 142.

Assuming that the series-connected tubes 142 and 143 are 40-watt tubes and that the coil 147 and its connecting leads 148 and 149 are omitted, the voltage required to operate said tubes in series would be about 900 volts. On the other hand, the connection of coil 147 across points 26 and 32 in series with tube 142 and in parallel with tube 143 reduces the voltage required to operate the two tubes in series to a value of approximately 600 volts.

The three-tube system shown in Figs. 13 and 14 illustrate an arrangement wherein two tubes are operated in series with each other on the inductive side of the system in parallel with a single tube connected in series with a current-limiting condenser on the condensive side of the system.

The transformer generally indicated at 155 in Figs. 13 and 14 is shown as a standard transformer comprising a primary coil 156 and a secondary coil 157 arranged on a central core leg 158 lying between outer legs 159 and 160, all of said legs being joined to end pieces 161 and 162. Primary coil 156 is connected across a source of alternating current potential 163 by leads 164 and 165.

On the condensive side of the system shown in Figs. 13 and 14 a single tube 167 is connected across coils 156 and 157 in series with a current-limiting condenser 168. In tracing the circuit connections of this tube, it will be noted that the left hand end of coil 157 is connected to the transformer side of condenser 168 by lead 169. The tube side of condenser 168 is connected to the left hand electrode of tube 167 by lead 170. The right hand electrode of tube 167 is connected to the right hand end of coil 156 by lead 171. The left hand end of coil 156 is connected to the right hand end of coil 157 at junction 172.

On the inductive side of the system shown in Figs. 13 and 14, two tubes 174 and 175 are operated in series with each other through the agency of two external choke or inductance coils 176 and 177 which are mechanically separate from each other and from transformer 155. As here shown each of the coils 176 and 177 is arranged on a central leg 178 lying between outer legs 179 and 180, all of said legs being joined to end pieces 181 and 182. Coil 176 is connected across transformer coil 156 and 157 in series with both of the lamps 174 and 175. Coil 177 is connected across transformer coils 156 and 157 in series with tube 174 and in parallel with tube 175. The circuit connections by which this is accomplished may be traced as follows:

The right hand end of coil 176 (Fig. 14) is connected, at junction 184, to the right hand end of lead 185. The left hand end of lead 185 is connected to lead 189 at junction 186. The left hand end of coil 176 is connected to the left hand electrode of tube 175 by lead 187. The right hand electrode of tube 175 is connected to the right hand electrode of tube 174 by lead 188. The left hand electrode of tube 174 is connected to the right hand end of transformer coil 156 by lead 189 which joins lead 171 at junction 190. The left hand end of coil 177 is connected to lead 185 at junction 184. The right hand end of coil 177 is connected to the right hand electrode of tube 174 by lead 191 which joins lead 188 at junction 192.

The tube 167 is operated by the transformer output voltage impressed across points 186 and 190, the current flow in said tube being limited to a proper value by the current-limiting effect of condenser 168.

On the inductive side of the system shown in Figs. 13 and 14 a high voltage is impressed on tube 174 and a small amount of current, just sufficient to establish and maintain an ionized and conductive condition, is allowed to flow through this tube by way of the current-limiting by-pass afforded by the coil 177 and its connecting leads. In this connection, it may be noted that the reactance of coil 177 is high enough to limit the by-pass current in tube 174 to the minimum required to maintain ionization.

Once current flow is established in tube 174, the voltage across tube 175 is effective to establish an ionized and conductive condition of tube 175 and to cause the proper amount of operating current to flow in both of these series-connected tubes, the coil 176 being designed to act as a current-limiting reactor which maintains the current flow in the series-connected tubes 174 and 175 within the required limits. In the absence of the current-limiting by-pass provided by coil 177 and its connections, a prohibitively high voltage would be required to operate tubes 174 and 175 in series.

In a system such as shown in Figs. 13 and 14 a power factor closely approaching unity can readily be obtained by proper design since the current in the transformer secondary coil 157 is approximately at the low value indicated by point 52 on the vector diagram shown in Fig. 9a.

The system shown in Figs. 15 and 16 illustrates an arrangement wherein three tubes 194, 195 and 196, are operated in series with each other by means of transformer 197 and three external reactance coils 198, 199 and 200, said reactance coils being mechanically separate from each other and from transformer 197.

Transformer 197 is shown as a standard shell-type transformer having a primary coil 201 and a secondary coil 202 arranged on a central core leg 203 lying between outer legs 204 and 205, all of said legs being joined to end pieces 206 and 207.

Each of the reactance coils 198, 199 and 200 is mounted on a separate core structure including a central leg 208 encircled by the coil and lying between outer legs 209 and 210, all of said legs being joined to end pieces 211 and 212.

In tracing the circuit connections shown in Figs. 15 and 16, it will be noted that primary coil 201 of transformer 197 is connected across a

source of alternating-current energy 214 by leads 215 and 216. The left hand end of primary coil 201 is connected to the right hand electrode of tube 194 by lead 217. The left hand electrode of tube 194 is connected to the left hand electrode of tube 195 by lead 218. The right hand electrode of tube 195 is connected to the right hand electrode of tube 196 by lead 219. The left hand electrode of tube 196 is connected to the right hand end of reactance coil 198 by lead 220. The left hand end of reactance coil 198 is connected, at junction 221, to the right hand end of the transformer secondary coil 202. The left hand end of secondary coil 202 is connected, at junction 222, to the right hand end of primary coil 201.

The left hand ends of reactance coils 199 and 200 are connected to the right hand end of secondary coil at junction 221 by leads 223 and 224, the lead 223 joining lead 224 at junction 225. The right hand end of reactance coil 199 is connected to the right hand electrode of tube 195 by lead 226 which joins lead 219 at junction 227. The right hand end of reactance coil 200 is connected to the left hand electrode of tube 194 by lead 228 which joins lead 218 at junction 229.

In the operation of the system shown in Figs. 15 and 16, the reactance coils 199 and 200 and their connecting leads afford current-limiting bypasses through which current is by-passed around tube 196 to effect an ionized and conductive condition of tubes 194 and 195. When this occurs the transformer voltage applied across tube 196 is immediately effective to establish an ionized and conductive condition of tube 196 and to cause the proper amount of operating current to flow through the three tubes in series.

The coils 199 and 200 are high reactance coils designed to limit the amount of by-pass current supplied to tubes 195 and 194 to the minimum required to establish and maintain an ionized and conductive condition of said tubes. The coil 198 is designed to act as a limiting reactor which functions, in the ionized and conductive condition of the three series connected tubes, to limit the operating current to the proper value.

In the foregoing I have described, merely by way of example, various thoroughly practical arrangements whereby the basic principles of my invention may be applied, economically, to effect instantaneous starting and operation of series-connected fluorescent tubes without employing operating voltages in excess of those permitted by existing safety regulations. Among other benefits flowing from the instantaneous operation of fluorescent tubes in series, in accordance with the principles of my invention, the following may be noted as being of particular importance:

(1) The cost of an instantaneous start fluorescent tube lighting fixture in which certain or all of the tubes are operated in series in accordance with my invention is substantially less than the cost of other instantaneous start fixtures having the same number of fluorescent tubes and is, in fact, the same or not substantially greater than the cost of comparable conventional slow starting fixtures which require starters, thermal devices, or relays, to operate satisfactorily and take six seconds or more to bring the tubes to a satisfactory condition of luminescence.

(2) The operation of fluorescent tubes in series, in accordance with my invention, lends itself to the use of any suitable source of alternating current energy including either standard or auto-transformers.

(3) In a fixture in which two or more tubes are operated by a single transformer, the operation of certain or all of the tubes in series in accordance with my invention makes it possible to easily achieve, by proper design, a power factor of over 90%, with resulting reduction of stroboscopic flicker and transformer heating to a minimum.

(4) Any kind or type of luminescent or gas-filled discharge tubes may be successfully and economically operated in series with each other in accordance with the teachings of my invention. However, cold cathode operation of the tubes is recommended to reduce flicker and extinguishment of the arc in cold weather.

(5) Fluorescent tube lighting systems embodying my invention are characterized by good wave form; by the absence of flutter, light pulsations, or other detrimental or annoying effects visible to the naked eye; and by the rapidity with which the arc is re-struck and full brilliance of the tubes achieved when power is restored after being accidentally or otherwise shut off.

(6) The operating characteristics of transformer-powered luminescent tube lighting systems embodying my invention are such that the cost of providing the required type of transformer, condensers and/or current-limiting reactances is not appreciably greater than the cost of a conventional transformer. One of the factors which keeps the transformer cost relatively low is that the condensive and inductive sides of the system are each served by transformer windings in which only series current is flowing.

(7) Another advantage of the present invention is the elimination of the conventional starter with its combination of mechanical and electrical parts which, by reason of wear, sticking and chattering, are frequently the cause of fluttering, flickering and non-starting of the tubes.

Having thus described the nature and advantages of my invention and various practical applications thereof, it will be understood that various modifications are contemplated within the scope and spirit of the invention as defined by the appended claims.

Having thus described my invention, what I claim is:

1. In a fluorescent tube lighting system, a source of alternating current energy, a plurality of fluorescent tubes connected in series with each other across said source, and a high by-pass impedance connected respectively to one terminal of said source and to a series connection between adjacent tubes, and a low impedance in series with all of said tubes and connected to the same terminal of said source as the first impedance, the impedances being in series across one of said tubes and being of such values that after the remainder of said tubes have become conductive the break-down voltage will be applied to said one of said tubes, all of said tubes being operated in series with each other at a voltage substantially lower than the sum of the break-down voltages required for each tube.

2. In a fluorescent tube lighting system according to claim 1 wherein there are only two tubes in series.

3. In a fluorescent tube lighting system according to claim 1 wherein there are more than two tubes connected in series and wherein the said low impedance is in series with all of said tubes, and there is a separate by-pass impedance connected to each series connection between adjacent tubes and the said same terminal.

4. A fluorescent tube lighting system according to claim 1 including an additional tube load, a transformer having a primary winding and two secondary windings in auto-transformer relationship, the primary and one of said secondary windings constituting the source of alternating current energy for the series connected tubes and the other secondary and the primary winding constituting a source of alternating current energy for the said additional tube load.

5. In a fluorescent tube lighting system according to claim 1 wherein the impedances are condensers.

6. In a fluorescent tube lighting system according to claim 1 wherein the impedances are reactance coils.

7. A fluorescent tube lighting system according to claim 1 including an additional tube load, a transformer having a primary winding and two secondary windings in auto-transformer relationship, the primary and one of said secondary windings constituting the source of alternating current energy for the series connected tubes and

the other secondary and the primary winding constituting a source of alternating current energy for the said additional tube load, said additional tube load having tubes connected in series, said other secondary transformer winding constituting a low impedance for limiting current flow in said last-mentioned series connected tube load, and a separate high by-pass impedance connecting the series connection between adjacent lamps of the additional tube load and the current source for the first-mentioned series connected tubes.

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