ELECTRONIC TUBE CONTROL FOR THEATER LIGHTING*

J. R. MANHEIMER AND T. H. JOSEPH**

Summary—*Modern theatrical practice requires a switchboard capable of controlling elaborate electrical effects in connection with stage spectacles. Three-color house lighting, four- and five-color stage effects, frequently involving as much power as 1500 kw., require a flexible, compact, easily controlled system for accurately and rapidly effecting the various combinations and changes of lighting.*

The reactance dimming electronic tube controlled switchboard here described is capable of presetting the intensities and combinations of lights, and easily controlling the effects required for several scenes in advance without interfering with the combinations for the scene in use.

Rectifier-tube control for stage-lighting systems may be classed as a rather recent development. Naturally, the question has arisen as to why such a system is used. The answer is simple.

First, due to the increased size of the newer theaters, the number of circuits to be controlled and their wattages have increased to such an extent that the resistance type of dimmer has become impracticable in many cases. The resistance dimmer needs considerable contact pressure to carry its load and, as a result, the muscular effort required to operate a large bank of dimmers makes it impracticable. Second, stage space is always at a premium, making it desirable as well as economical to locate the dimmers at a remote point and to control them from a pilot-board at stage level. This, of course, might be done with motor-operated dimmers, but with such a system the flexibility afforded by a rectifier tube controlled system can not be achieved. Furthermore, the maintenance of such a system is an endless and expensive task. Third, for a succession of rapid light changes, presetting of resistance type dimmers for each change after the first is impracticable, but is conveniently accomplished with a tube-controlled board. Toward the end of attaining a stage-lighting system that is compact, easy to operate, and economical to maintain, the development of the tube type of stage switchboard has been aimed.

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** E-J Electric Installation Co., New York, N. Y.

The so-called preset switchboards providing only for the presetting of circuits have long been familiar. The real value of presetting lies in being also able to preset dimming. In order to do so, it is necessary to have a control unit so small that five or more can be mounted in a space much smaller than that originally occupied by a single control on the old type of preset board. Only tube control has made this possible; hence the development in this line. As the development advanced, it was found that other desirable features such as propor-

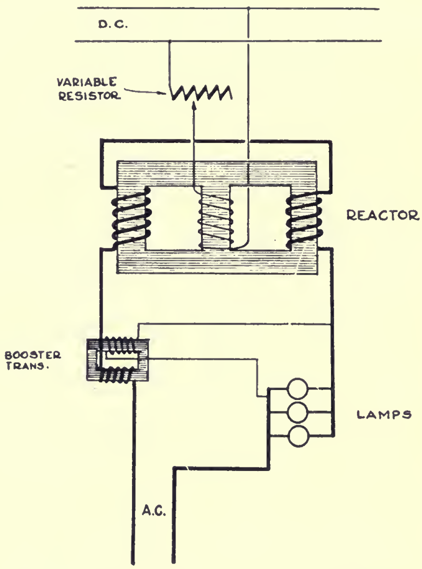

FIG. 1. An elementary reactance dimmer-control system.

tional fading, compact master control, and efficient remote control could easily be realized.

Although several types of tube controlled theater boards are in use at the present time, this paper will restrict itself to a description of one of the latest of these types which has just been put into operation in the Center Theater at Radio City, New York, N. Y.

In order to describe the system and explain wherein it differs from other tube control systems, let us first consider an elementary reactance dimmer-control system such as shown in Fig. 1. This consists of a reactance dimmer in series with the lamps which are connected across the a-c. power supply. The dimmer reactor consists of a three-legged saturable core reactor having an a-c. coil wound upon each outside leg and a d-c. coil upon the center leg. The two a-c. coils are connected in series with each other and with the lamps. The d-c. coil is connected to a variable source of direct current.

With no excitation in the d-c. coil, the impedance of the two a-c. coils is such as to cause a voltage drop in their windings sufficient to limit the lamp voltage to the desired minimum. The connections of the coils are such that in the center leg of the reactor the a-c. flux of each coil at any instant is equal and opposite to the flux of the other coil. Therefore, no alternating voltage is induced in the d-c. coil. When the latter is energized to the point of saturation of the iron in the reactor, the a-c. coils are unable to induce a voltage in their own windings, and the lamp voltage is equal to the line voltage less the drop due to the resistance in the a-c. coils. Intermediate values of lamp voltage are attained by intermediate values of direct current in the d-c. coil.

The intensity of light is varied by changing the small amount of direct current passing through the d-c. coil, "full bright" being attained when the direct current is at its maximum and "black out" when at its minimum. In order to burn the lamps at full brilliancy when the reactor is saturated, it is necessary to provide means of compensating for the voltage drop due to the resistance of the reactor windings. This is accomplished by a small booster transformer having a secondary voltage equal to the drop in the reactor and connected in series with the lamp circuit. The primary of this transformer may be connected to any source of alternating current of the proper voltage.

Reference to the diagram of the tube-controlled circuit in Fig. 2 will immediately suggest a great similarity to the circuit previously described. In the first place, the reactance dimmer is the same. The source of direct current consists of a full-wave rectifier tube; but the variable resistance for controlling this direct current has been replaced by the "hysterset," which is a device for enabling small amounts of power to control large amounts of power. The "hysterset" is controlled by a variable resistor connected across its low-voltage control circuit. Referring to Fig. 2, its mode of application is as follows:

Starting at the pilot switchboard, two transformers, of 120/12 volts, connected across two phases of a three-phase supply, provide the proper supply voltages. Across the outer ends of this supply is connected the control resistor, which has an adjustable slider. A small copper-oxide rectifier is used, having one anode connected to the adjustable slider and the other to one side of the transformer secondary. The cathode circuit of the rectifier is connected through the control coil of the hysterset to the middle point of the secondary. The pur-

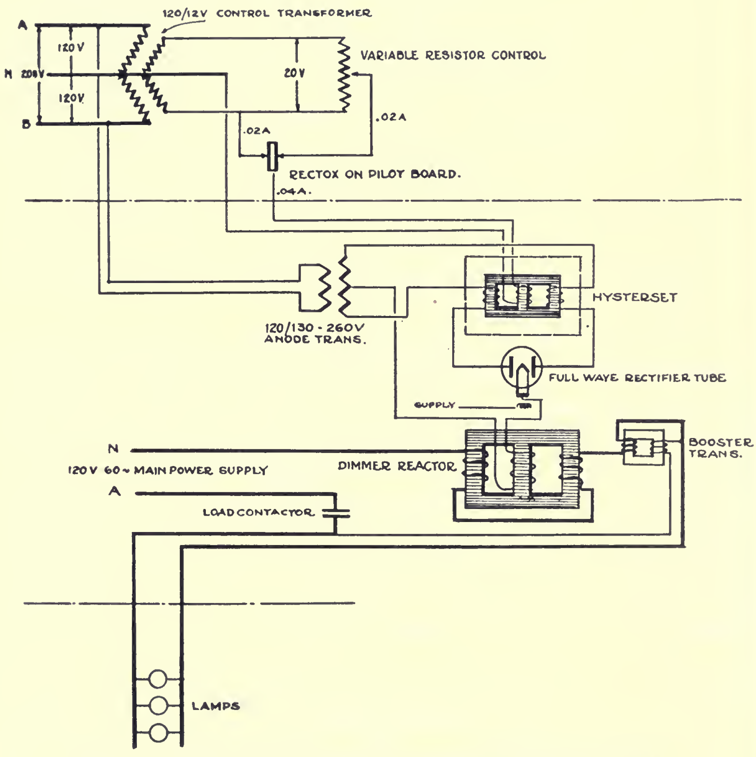

FIG. 2. The tube-controlled circuit employing the *hysterest*.

pose of this is to supply to the hysterset direct current which can be controlled as follows:

When the slider is in the lowest position, both anodes of the rectifier are connected to the same source, so that there is no difference of potential or phase angle between them and the rectifier acts as a half-wave rectifier with the anodes in parallel. The reactance of the control coil then permits only a minimum amount of current to flow, corresponding to the "black out" position of the dimmer. If the slider is moved to the other end of the resistor, the rectifier acts as a full-wave rectifier with the anodes 120 degrees out of phase. This allows maximum current to flow in the control coil, corresponding to the "full bright" position of the dimmer. Intermediate light intensities are attained at corresponding intermediate settings of the resistor.

The control coil operates through the hysterset so that during each

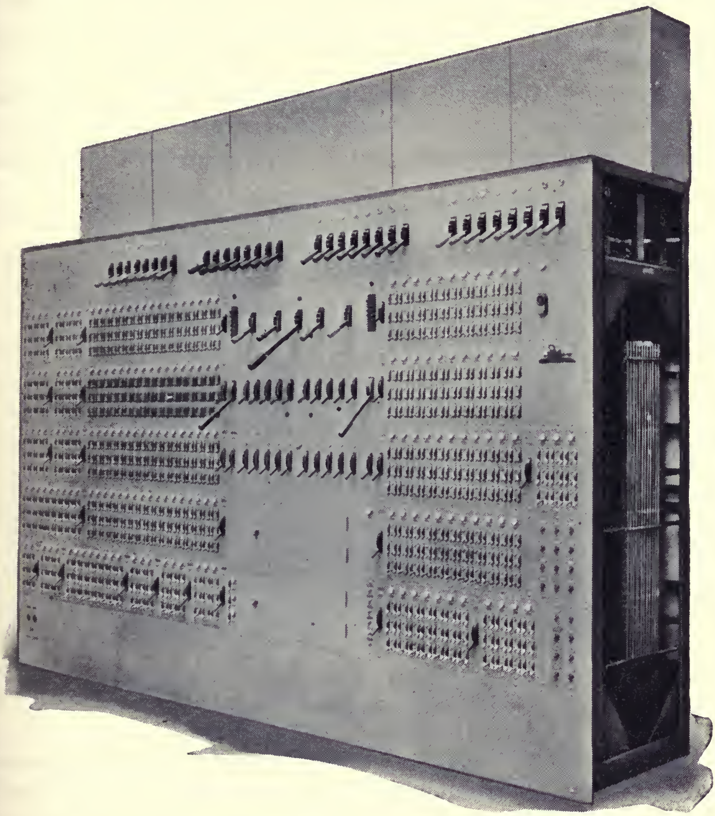

FIG. 3. Front view of the tube-controlled pilot board in the Center Theater, New York, N. Y.

half cycle the iron of the anode reactor is conditioned so as to predetermine the amount of current to flow during the next half-cycle of operation. The output of the hysterset is fed into a full-wave rectifier tube, the cathode of which is connected through the d-c. coil of the dimmer reactor back to the mid-point of the anode transformer. Thus by varying the pilot circuit, as previously described, the direct current in the d-c. coil is varied and the voltage at the lamps changed accordingly, as illustrated in Fig. 1.

Fig. 3 is a front view of the tube-controlled pilot board in the Center Theater. The individual sections at the left consist of one hundred and thirty stage controls, each with five presets and a rehearsal section, arranged according to color: top row, amber; next, red, green, and blue. On the right are fifty-one similar control units for the house lights.

The top row of thirty-two quadrants with handles control Selsyn generators operating four color frames in every incandescent spot and flood on the stage and in the house. The row below this, in the center

FIG. 4. Part of one of the attic reactor racks, with the reactors in place.

section, contains the Selsyn color masters and their grand master. Below these are smaller quadrants used as scene masters, five for stage and five for house. In the lowest row are the supplementary scene masters, five for stage and five for house lights. Between the row of scene master controls and supplementary controls are two buttons. The button at the left is used for "black out stage" and the button at the right for "black out house."

At each side of the center section are the color masters and stage and house grand masters. The two large handles at each side of the center panel are the stage and house faders. Immediately above each is a bank of five pairs of interlocking push-buttons for selective fading from one scene to any other preset scene. Scenes may be faded one into the other in any sequence or combination. Immediately at the center is a lock that shuts off the entire system except the work-light switches at the lower right. At the left and across the bottom left are individual controls and group masters to control pockets in the stage floor and elsewhere. At the upper right is a guarded "panic light" switch, which in conjunction with two others in the house, throws on the "full bright" amber house lights regardless of the position of the dimming controls.

Fig. 4 shows part of one of the attic reactor racks with the reactors in place. There are two reactor rooms, one in the basement and one on the gridiron level, so as to shorten the lengths of the circuits and so reduce the voltage drop. Circuits supplying the footlights, pockets, proscenium and portal floods, tower spots, *etc.*, are connected to the basement reactor group. Circuits running to borders, all top lights, and auditorium ceiling are connected to the attic reactor group.

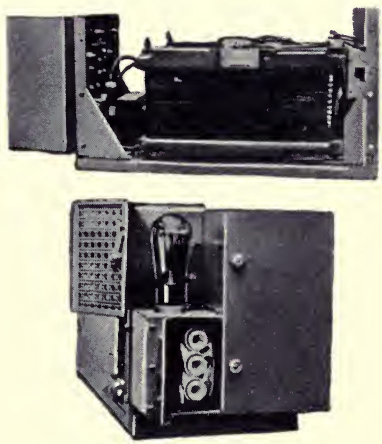

FIG. 5. (*Upper*) A reactor unit, from the side, without the tube panel; (*lower*) tube panel hysterset assembly.

Fig. 5 shows the side of a reactor unit without the tube panel, which plugs into the right-hand end. The tube panel hysterset assembly is shown just below the reactor. Mounted at the left end of the reactor is a contactor, one being supplied for every section controlled from the pilot board.

Fig. 6 is a simplified diagram of the color master control, which operates only in conjunction with the rehearsal presets, indicated in the diagram as individual resistors *1*, *2*, and *3*. The various color masters are connected to the same source of power as the other control units. The individual rehearsal units may be transferred from independent bus to master control bus by small double-throw switches.

Full-range control can be effected with the individual resistor controls provided the master variable autotransformer control is in the "full bright" position when the individual controls are thrown on the master bus; or, with the individual resistor controls when thrown on the independent bus. When on master control, the intensities of the various lamp groups can be varied collectively and proportionately by operating the master slider.

Fig. 7 shows scene master and supplementary scene master for two scenes connected for fader operation. This simplified diagram does not show the interlocking selective buttons and switches for optional transfer to fader control. By operating the proper selective buttons, the fader can be preset and so connected that with a single operation of the fader lever one scene can be "faded out" and another scene "faded in" proportionately. After the fader lever has reached the limit of its motion, a new combination of the selective buttons can be chosen so that the existing scene may be "faded-out" and the next scene "faded-in," *etc.*

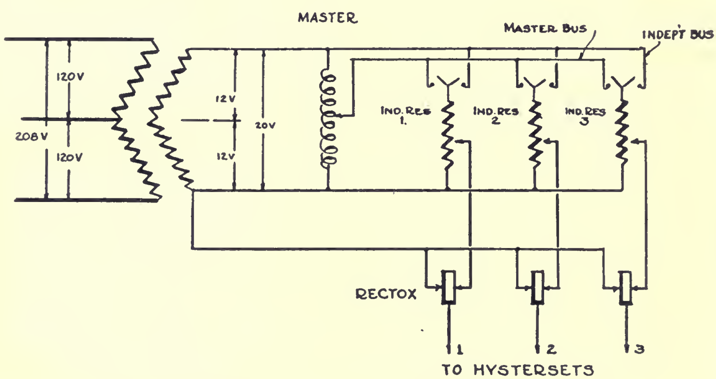

FIG. 6. Simplified diagram of color master control.

The lighting intensities of the various light sources correspond to the calibrated settings of the sliders on the individual presets, so that a combination of intensities from various light sources is possible ranging from nearly "black out" in certain groups to "full bright" in others. By setting some of the lights in a scene on a scene master and the remainder on the supplementary master, two master controls can be employed for each preset scene, permitting in effect ten preset scenes, although the board is known as a five preset board. Any set-up on the supplementary master can be transferred to the corresponding scene master without interrupting the continuity of the lighting by operating a small double-throw switch so as to put the entire lighting under the control of the one scene master. This feature is required when it is necessary to "take out" in a single operation all the lighting that may have been "brought in" by the operation of several controls.

Fig. 8 is a photograph of one of the preset variable resistor control panel units. This unit measures $2^1/_4$ inches in width and 12 inches in height; which gives some idea of the compactness of this type of control, considering that in this small space the equivalent of six dimming controls can be included. The space ordinarily occupied by one dim-

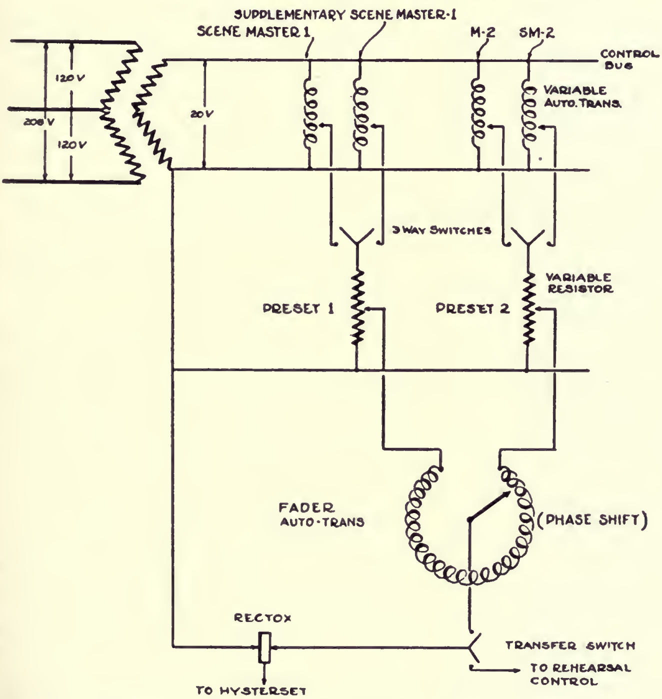

FIG. 7. Diagram of scene master and supplementary scene master, for two scenes connected for fader operation.

ming plate and its corresponding circuit switch requires considerably more than this.

At the top of this assembly is a pilot light, which indicates when the contactor in the reactor room closes. Below it are the preset controls for five preset scenes and one rehearsal. Each of the five preset scene controls is connected to a small double-throw switch used to transfer the corresponding preset from the scene master to the supplementary master, or *vice versa*. The rehearsal control is also equipped with a similar small double-throw switch for transferring its control from the color master to the independent bus, or *vice versa.* Each of the quadrants of the individual presets is equipped with a calibrated scale to indicate the intensity of the light for which it is to be set. These calibrations are based upon visual brightness, and not upon photometrically measured intensities.

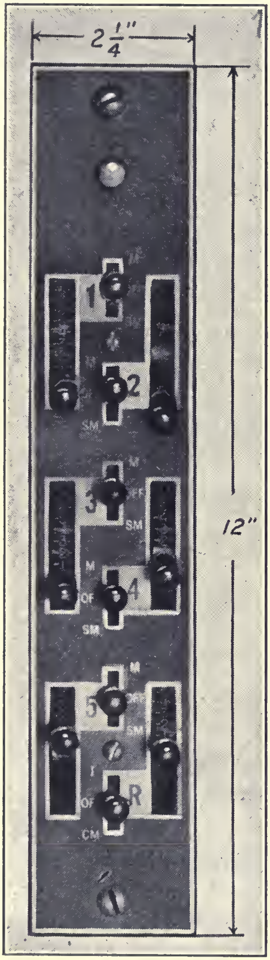

FIG. 8. One of the preset variable resistor control panel units.

This, in brief, describes the fundamental principles of the hysterset control. Of course, special features such as elaborate master control, preset control, extended control, *etc.*, are attainable with this system. Its advantages are many compared with the commonly used systems.

The tube is a simple two-element rectifier involving none of the delicate features of a grid-controlled tube. The operation of the tube is not affected by changes in ambient temperature. It is possible to replace one tube with another without having to recalibrate the tube or the circuit. The life of this type of tube is long, and the cost of replacement low. The equipment at the Center Theater has already seen approximately 1500 hours of service without a tube failure and no indication of any. The current required to operate the controls is very small, a total of over 750 kw. of lamp load being controlled by less than 2 kw. at the control board. For example, the main ceiling 70 kw. is controlled by a minute control consuming but a few watts. Great flexibility of the control is achieved, and the change in light level is so smooth that a comparable dimmer plate would need about 750 contact buttons to equal it. As to compactness, the pilot board occupies a space 11 feet 5 inches long, 26 inches deep, and 6 feet 6 inches high, and is operated by one man. Heat-producing apparatus is avoided on the stage, and the system is completely silent in operation.

The real test of a switchboard is its effectiveness upon the audience in its control of light. *The Great Waltz* performance, now being staged at the Center Theater, demands the use of the entire 650 stage presets on the board, and light control changes occur approximately every ten seconds and at times every second. The equipment and entire system were installed under the supervision of the C. R. Place Engineering Associates. The switchboard was manufactured and supplied by the Westinghouse Electric & Mfg. Co., in combination with the hysterset control, which is a recent development of the Ward-Leonard Company. Similar equipment, but differing slightly in certain features, is at the present time being installed in the Metropolitan Opera House in New York, manufactured and supplied by the General Electric Company, and installed by the E-J Electric Installation Co.

DISCUSSION

MR. HASKELL: What is the difference between the board now installed at Rockefeller Center and other tube switchboards?

MR. JOSEPH: The principle of most tube switchboards is the same, namely, to control a large current by means of compact and cool apparatus on the stage floor.

Tube boards depend primarily upon the use of reactors for the actual dimming. The first reactor board for theaters was installed by the wiring department of the United Electric Light & Power Company in Daly's Theater at 29th Street and Broadway, in 1888. The change of reactance was achieved by pushing an iron core in and out. After the board had been completed, Mr. Daly was requested to observe its operation. The first core pushed in dimmed the lights, but hummed like a hive of angry bees. The next core was somewhat smaller, and the hum assumed a higher tone. With the third and fourth cores, the result was similar except for the tone. Mr. Daly looked and listened. He asked whether the noise was necessary, and was told that it was unavoidable. "Very well," he said, "throw the whole thing out into the street." That was the end of the first reactor board.

Tube control can be broadly divided into two types: the Westinghouse-Ward Leonard type, in the Center Theater, and all the others. The control in the Center Theater, described in the paper, employs a regular full-wave rectifier tube, one for each reactor, for supplying the varying direct current required by the main reactor, and is controlled by a small reactor and associated apparatus called the *hysterset*.

The other types furnish the varying direct current directly to the reactor through grid controlled tubes. For the larger reactors a second tube is added, and connected in parallel to the first. Other types use grid controlled tubes, which are cascaded, as in a radio receiver, progressing from small currents and small tubes to large currents and larger tubes.

Either a potentiometer or a small inductor may be used for varying the grid current at the pilot board. Moving the inductor armature increases or decreases the magnetic linkage and varies the pilot current accordingly.

Each maker has different means of accomplishing the various master and fader controls. A complete comparison of these and other details would occupy more time and space than is available.

MR. HASKELL: How many tubes are used in this board as compared with the other one?

MR. JOSEPH: One tube for every circuit. On the previous board, which this replaces, eight tubes were in the control unit and two tubes in the reactor set, making ten tubes per unit, instead of one.