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Fig. 1a

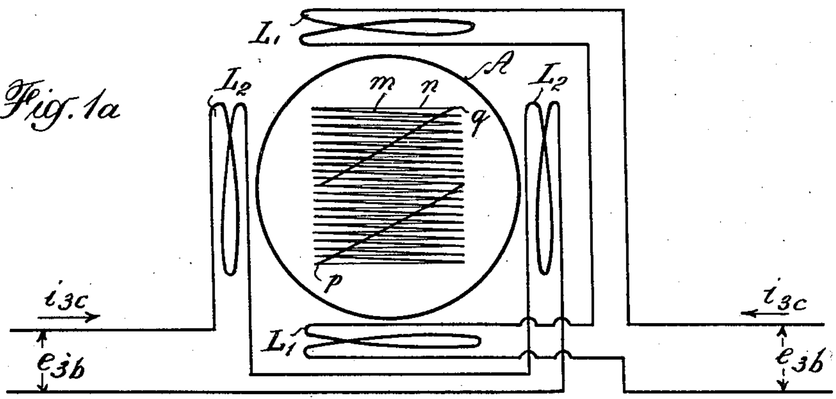

Fig. 1b,

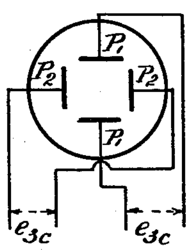

Fig. 1c,

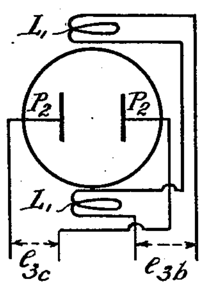

Fig. 1d,

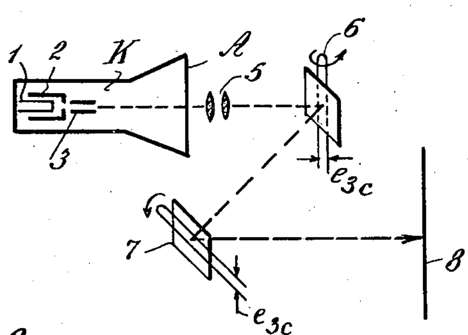

Fig. 2,

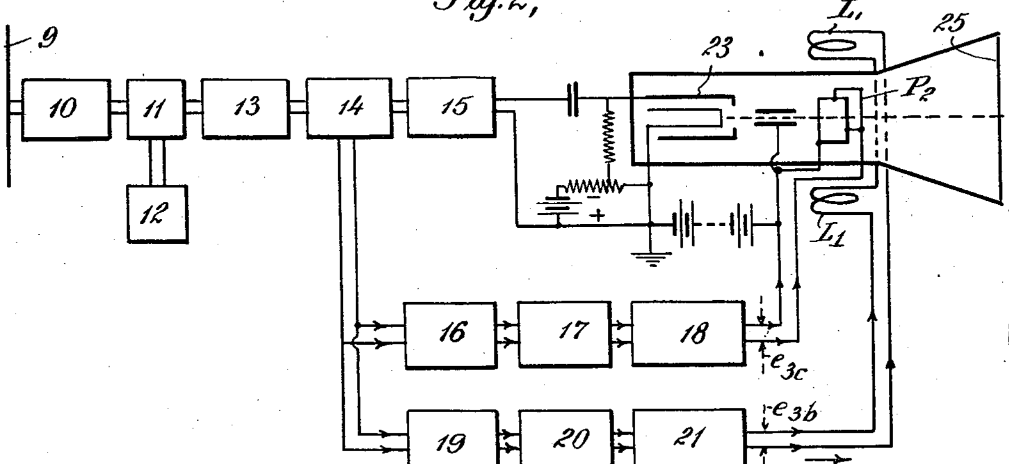

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Fig. 3a

Fig. 3f, Fig. 3g,

Fig. 3b, Fig. 3c, Fig. 3d Fig. 3e

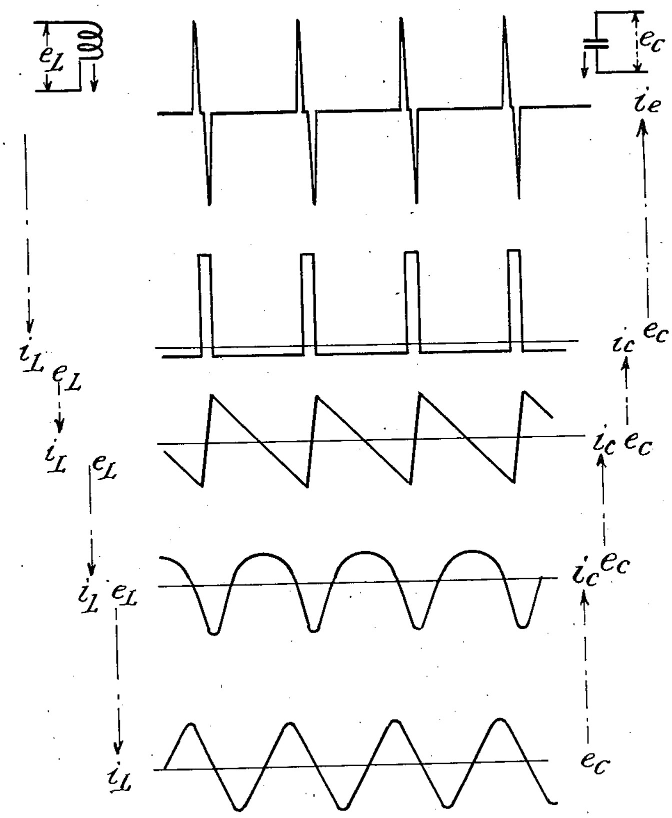

Fig. 4a, Fig. 4b, Fig. 4c,

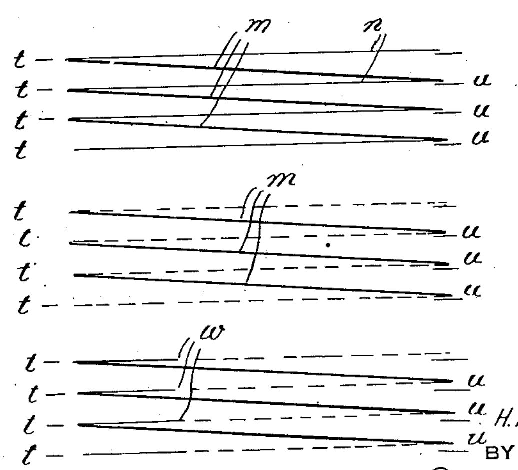

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Fig. 5a,

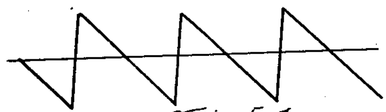


Fig. 5b

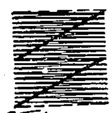


Fig. 5c,

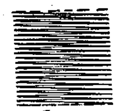


Fig. 5d,

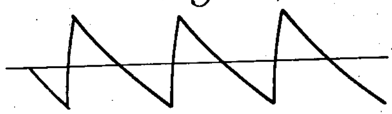


Fig. 5e,

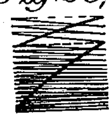


Fig. 5f

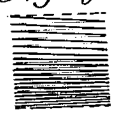


Fig. 6a

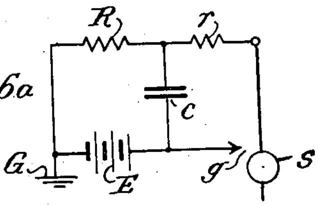


Fig. 6d

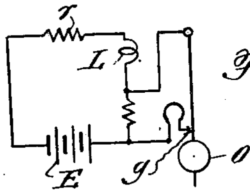


Fig. 6b,

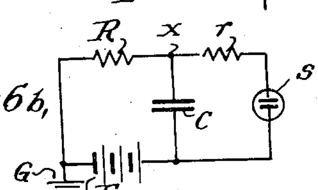


Fig. 6e,

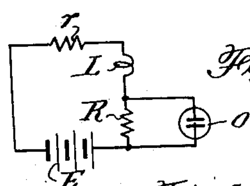


Fig. 6c

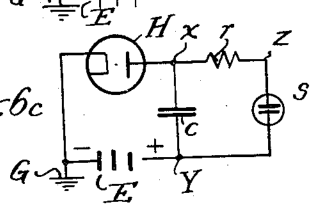


Fig. 6f,

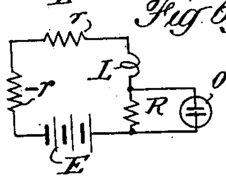


Fig. 6g.

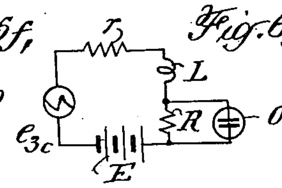


Fig. 9a,

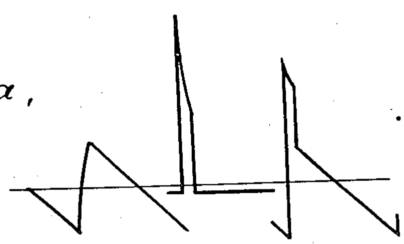


Fig. 9b,

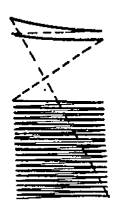


Fig. 9c,

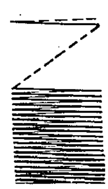


Fig. 10a,

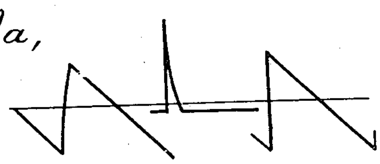


Fig. 10b

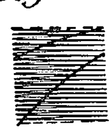
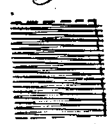


Fig. 10c,



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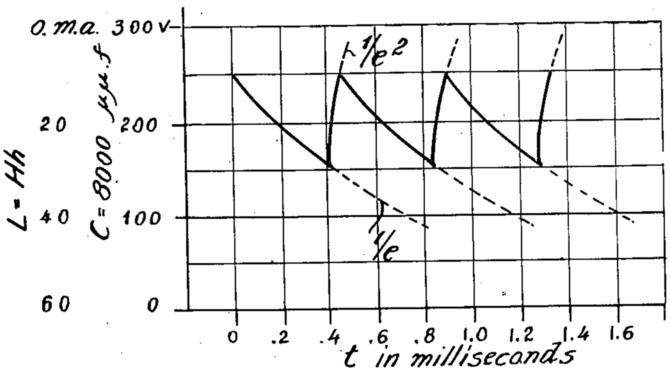

Fig. 7a,

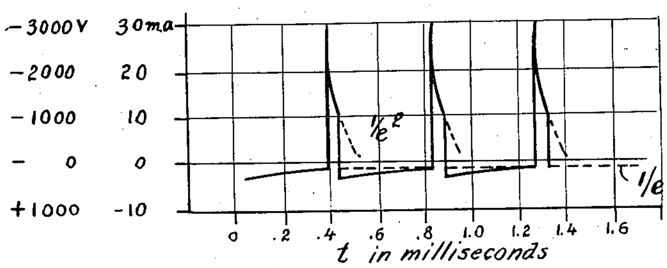

Fig. 7b,

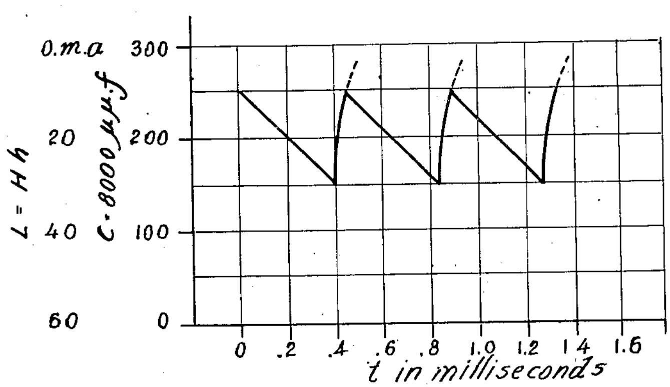

Fig. 8a,

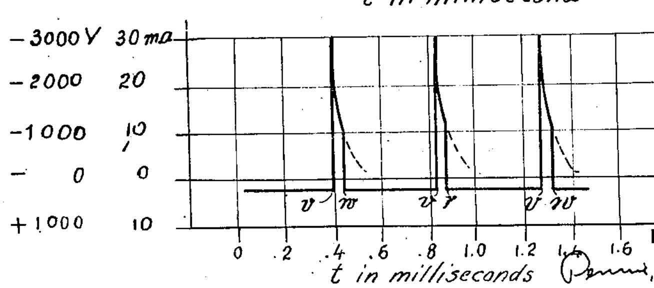

Fig. 8b,

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Fig. 11a,

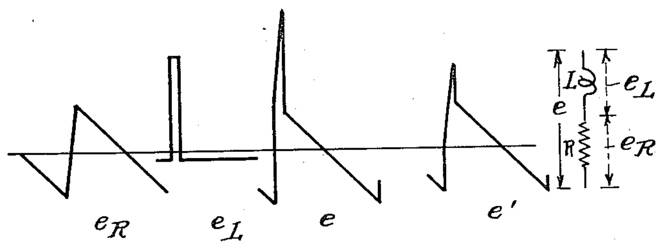


Fig. 11b,

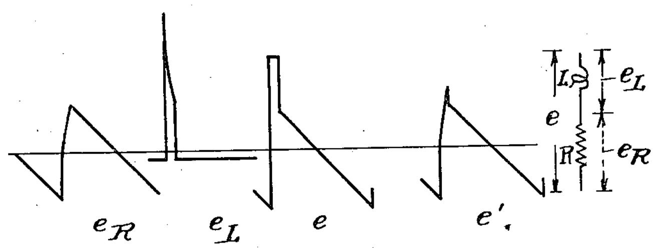
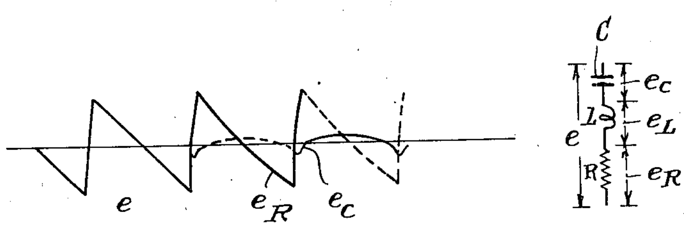


Fig. 11c



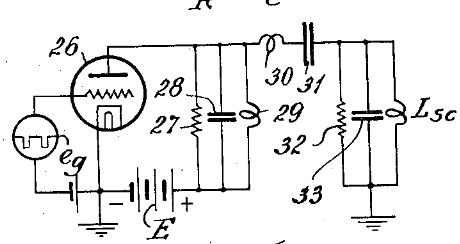
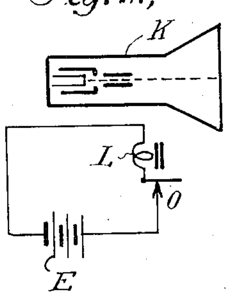


Fig. 13a,

Fig. 12,



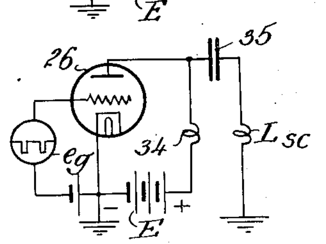


Fig. 13b,

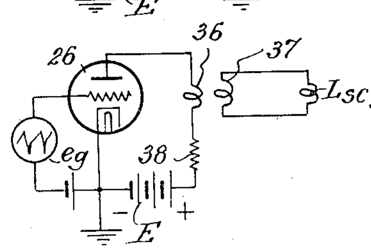


Fig. 13c,

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Fig. 14,

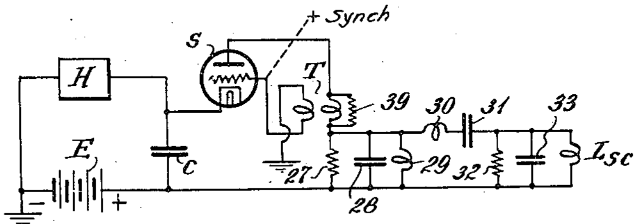


Fig. 15,

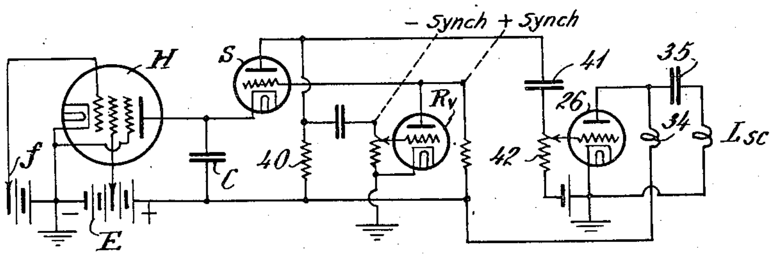


Fig. 16,

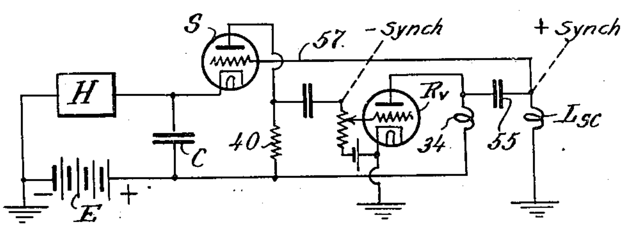


Fig. 17,

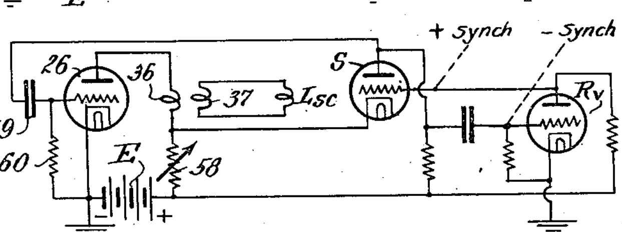


Fig. 18,

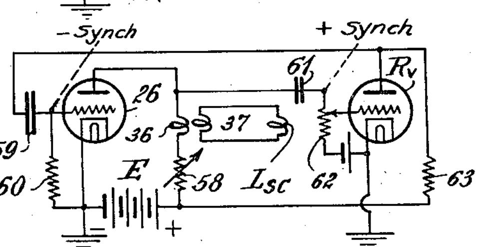
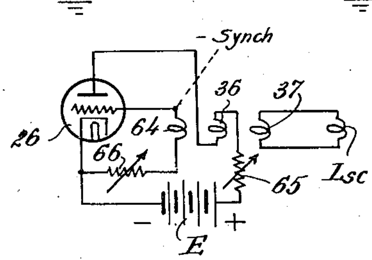


Fig. 19a,



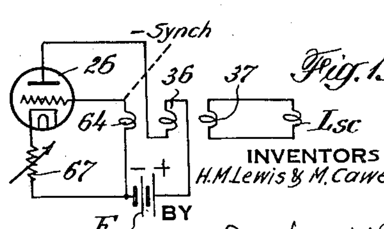


Fig. 19b.

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Fig. 20,

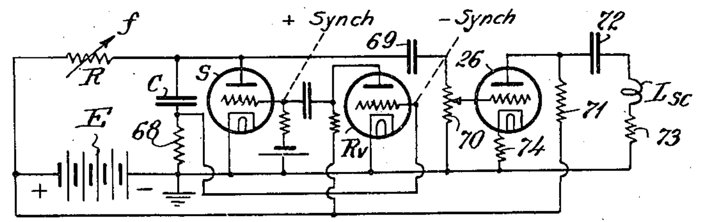


Fig. 21,

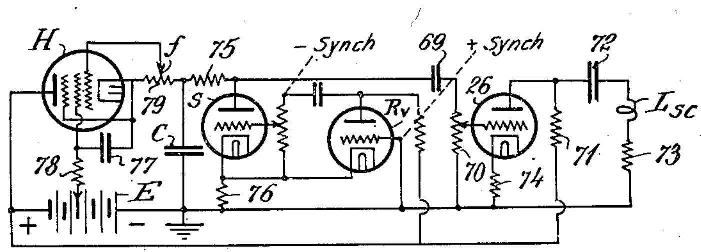


Fig. 22,

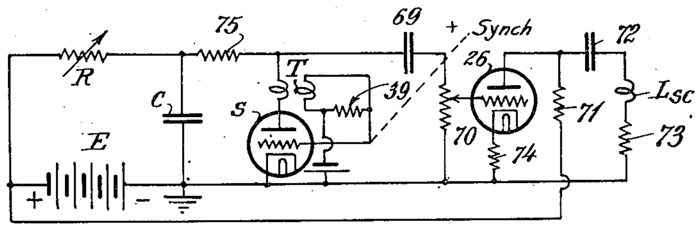


Fig. 23,

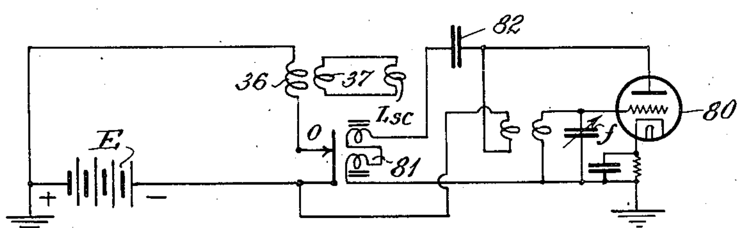
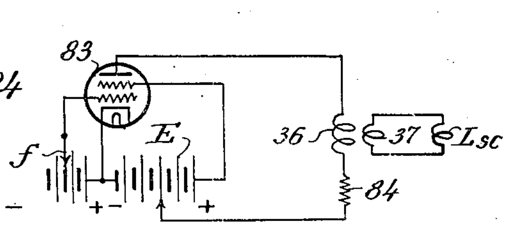


Fig. 24



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Patented May 31, 1938 2,118,977

UNITED STATES PATENT OFFICE

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TELEVISION APPARATUS

Harold M. Lewis, Douglaston, Long Island, and Madison Cawein, Manhasset, N. Y., assignors to Hazeltine Corporation, a corporation of Delaware

Application October 8, 1934, Serial No. 747,324

8 Claims. (Cl. 250—27)

This invention relates to the generation of electrical voltages and currents of complex wave forms. Particularly, it relates to the production of alternating currents and voltages of "saw-tooth" and related wave forms for use in television. The invention further relates to the utilization and synchronous control of such voltage and current wave forms to effect scanning in television.

A primary object of the invention is to produce voltage of saw-tooth wave form to serve as an electrostatic control of scanning in a cathode ray television receiver. Another primary object of this invention is to produce current of saw-tooth wave form through inductance to provide the field for magnetic control of scanning in a cathode ray television receiver. Another object of this invention is to provide circuits and apparatus for generating the saw-tooth and related wave forms in a precisely controllable and economical manner for use in television. Another object of the invention is to generate voltage and current wave forms related to the saw-tooth wave forms which will serve to govern or control the generation of voltage or current of saw-tooth form.

These and other objects of the invention will be clear from the specification which follows particularly as it relates to the description of the drawings in which:

Figs. 1*a*–1*d* inclusive, illustrate as applied to a cathode-ray tube, the manner in which voltages and currents of saw-tooth and related wave forms are employed to effect scanning in a television receiver.

Fig. 2 is a schematic diagram of a cathode-ray television receiver to illustrate the essential units required for receiving, scanning and controlling a television image.

Figs. 3*a*–3*e* inclusive, graphically depict a so-called derivative series of wave forms of which the saw-tooth form is one, to illustrate the voltage and current relationships relative to pure reactances, such as inductance and capacity shown diagrammatically in Figs. 3*f* and 3*g* respectively.

Figs. 4*a*, *b* and *c*, are graphs explanatory of the correct use of the saw-tooth wave forms in scanning the lines in a television picture.

Figs. 5*a*–5*f* inclusive, are graphs similar to those of Fig. 4, illustrative of the use of the saw-tooth wave form for scanning at picture frequency.

Figs. 6*a*–6*g* inclusive, are a series of fundamental circuits pertaining to the generation of voltages and currents of saw-tooth and related wave forms.

Figs. 7*a* and *b* and Figs. 8*a* and *b*, are diagrams of the wave forms of current and voltage resulting from operation of certain of the Figs. 6*a* to 6*g* circuits.

Figs. 9*a*, *b* and *c*, and Figs. 10*a*, *b* and *c*, are graphs illustrating the use of combined saw-tooth and impulse wave form for scanning in television.

Figs. 11*a*, *b* and *c*, are graphs illustrating wave forms suitable for causing current of saw-tooth wave form to flow in an impedance.

Fig. 12 is to a simple form of inductance in series with resistance type of generator, designated as the L/R type.

Figs. 13*a*, *b* and *c*, show vacuum tube arrangements for utilizing impulse, or impulse plus saw-tooth voltage wave forms to cause a saw-tooth wave form of current to flow through inductance.

Fig. 14 shows a resistance-capacity or R, C type of generator operating as an impulse voltage source for a scanning inductance.

Fig. 15 shows a similar resistance capacity type of generator arranged to function as an impulse generator for causing saw-tooth wave form of current to flow through an inductance.

Fig. 16 is a simplified circuit developed from Fig. 15.

Figs. 17, 18, 19*a* and 19*b* represent strictly L/R type generators of saw-tooth currents.

Figs. 20, 21 and 22 show the use of resistance-capacity type generators as properly poled sources of saw-tooth plus impulse voltage for grid control of vacuum tubes whereby saw-tooth current is caused to flow through inductance in the tube output circuits.

Fig. 23 is a vacuum tube arrangement simulating the fundamental L/R circuit of Fig. 16.

Fig. 24 illustrates the use of a dynatron as an L/R generator of saw-tooth current through an inductance.

The present application is one of a series of related copending applications to the same inventors, which in aggregate, describe a complete television transmitting and receiving system employing saw-tooth and related wave forms for line and picture scanning. In copending application of H. M. Lewis, Serial No. 747,070, filed October 5, 1934, there is described the transmitting portion of the system utilizing substantially saw-tooth scanning for generating the image or vision frequencies and also synchronizing impulses for controlling the scanning action of the receiving apparatus.

The present application is directed more specifically to the generation and synchronized control in the receiving apparatus of the saw-tooth line and picture scanning impulses.

It is contemplated that a television modulated carrier wave having such essential components as those described in the above mentioned of the copending applications, or its equivalent, is to be received to provide the vision frequency signals and control impulses referred to in this application for reproducing the image at the receiver. The present application therefore, is restricted to just so much of the descriptions of the copending applications as is requisite to an understanding of the novel aspects of this application.

In the several drawings, elements which perform the same function in each case, are similarly labeled; those of a fundamental nature being labeled by letters. Other elements are labeled numerically.

Referring to Fig. 1, A represents the luminescent-screen end of a cathode-ray tube K, upon which the scanning traces are indicated as they would appear in their ideal form when no signal is being received and applied to modulate the grid of tube K to control the intensity of the electron beam striking the screen. This ideal trace is of saw-tooth wave form in that each line is a linear trace from left to right (indicated by heavy line *m* to represent a constant value of illumination of the screen) and a rapid (practically zero time) retrace from right to left (indicated by a light line *n*) since practically no electrons strike the screen in this brief retrace interval and the illumination is therefore weak. Similarly, the succession or rate at which the lines are traced is shown to be linear with time from top to bottom of the screen since the lines *m* and *n* are evenly spaced for the 20 lines shown and the retract *p, q* from bottom to top of the picture is shown to be rapid in that it occurs in the time required for two lines to be traced; and hence these two lines appear oppositely sloped in the picture retrace. Thus, in the example illustrated the line frequency *m, n* saw-tooth wave form has an almost infinite ratio between time of trace and retrace, and the picture frequency *p, q*, saw-tooth wave form has a ratio of trace to retrace shown as 10 to 1. This manner of scanning the picture from left to right and from top to bottom is termed rectilinear scanning.

At the present time, for a television picture of reasonable quality, the number of pictures transmitted per second may be taken as 24, and the line frequency taken as 2880 per second. At least this is a sufficient definition of quality to serve in this application for purposes of describing the inventions.

The ratio of picture trace to retrace time is in practice about 40 to 1 (much better than shown in the illustration). Hence, with the line frequency of 2880 per second, there are 117 lines in each picture and three lost in the picture retrace. This ratio has a correspondence dimensionally to the ratio between the height of picture in a standard 35 mm. motion picture film and the opaque space separating adjacent picture frames (the film to space ratio being, in fact, about 30 to 1). Hence to scan motion picture film as described in the mentioned copending application Serial No. 747,070, only the time required for three or four lines can be lost in the retrace without losing a part of the picture height. As for the line frequency, a reasonable trace-to-retrace ratio in practice is about 10 to 1 which is far from the ideal of zero time shown in Fig. 1.

To cause the cathode ray to scan the screen it may be deflected by magnetic or electro-static fields. Magnetic deflection is illustrated in Fig. 1. The coils L_1, L_1 serve to provide the field for the picture frequency scanning while L_2, L_2 similarly serve to provide the field for line frequency scanning. Since the magnetic field changes proportionally to the current flowing in these coils, the current through L_1, L_1 must have a saw-tooth wave form recurrent at the picture frequency *p, q* rate, for example 24 per second; and the coils L_2, L_2 must carry current of saw-tooth wave form at the line frequency *m, n* rate, such as 2880 per second.

In order readily to understand the nature of the voltage required to cause such a current in the scanning coils, and to arrive at other voltage and current relationships which may be desired, a series of wave forms related to the saw-tooth wave form has been plotted and is shown in Figs. 3*a* to 3*e* inclusive. This may be termed a "derivative series", since any of the wave forms shown is the mathematical derivative of the wave form immediately below it in the series. The utility of this series as it stands relates to pure reactance, since fundamentally the voltage e_L across an inductance, Fig. 3*f*, is the derivative of the current i_L through the inductance, and the current i_c through a condenser, Fig. 3*g*, is the derivative of the voltage e_c across the condenser. Hence using the notation at the left of the figure, if a current through a pure inductance has any of the wave forms shown, the voltage across the inductance must be of the wave form shown immediately above, and if a voltage across a pure condenser has any of the wave forms shown the current through the condenser is of the wave form shown immediately above in the series. Fig. 3*c* is the desired wave form for scanning and is shown as providing a ratio of 10 to 1 in the time of trace to retrace. Fig. 3*a* will be referred to as a double-impulse; Fig. 3*b* as an impulse; Fig. 3*c* as a saw-tooth, and Fig. 3*d* as a parabolic impulse wave form. The form Fig. 3*e* requires cubical equations to represent it mathematically.

In Fig. 1*a*, the current in coils L_1, L_1, and that in coils L_2, L_2 is labeled i_{3c} to indicate its wave form as being that of Fig. 3*c* and the voltages applied in both cases are necessarily of impulse wave form and hence labeled e_{3b} to indicate the wave form as being that of Fig. 3*b*.

In Fig. 1*b* the cathode ray tube K employs deflecting plates for electrostatic scanning, wherein P_1, P_1 are the deflecting plates for the picture frequency and P_2, P_2 the deflecting plates for the line frequency scanning. Since the deflection of the electron stream is proportional to the voltage between the deflecting plates, the voltage across P_1, P_1 should be saw-tooth as indicated by the notation e_{3c} and that across plates P_2, P_2 similarly should be saw-tooth in form as labeled e_{3c}.

Fig 1*c* illustrates magnetic deflection, coils L_1, for the picture frequency and electrostatic deflection, plates P_2, for the line frequency, and hence the voltage required to cause saw-tooth current in L_1, L_1 is of impulse wave form e_{3b} as indicated, and the voltage across plates P_2, P_2 is of saw-tooth form e_{3c}.

The saw-tooth wave is also important in mechanical systems of scanning, which do not use rotating elements but which, nevertheless, must accomplish rectilinear scanning. For example, if a light valve is to be employed to vary the light intensity in accordance with the picture detail and the light is then to be scanned to spread a pattern on a screen similar to the pattern in Fig. 1*a*, then the arrangement of Fig. 1*d* is a solution requiring the use of saw-tooth wave forms. In this figure the cathode dry tube is the source of light as well as the light valve, having in its simplest form a cathode 1, a control grid 2, an accelerating apertured anode or plate 3 and fluorescent screen A. The vision frequencies which represent the picture detail are, of course, applied as voltage variations between 1 and 2 to control the number of electrons which pass through 3 and hence produce light in proportion to their number on striking the fluorescent screen A. No special elements have been indicated here or in the preceding representations of the tube to control the focus of the ray striking the screen, since such focus may be controlled by electrostatic or magnetic fields as best serves the construction of the particular tube employed. Lens 5 serves to focus the spot of light from A on screen 8 via the mirror surfaces of oscillograph-type vibrator mirrors 6 and 7 which determine the path of the light. It will be clear from the description of Fig. 1*a* that vibrator 6 must act to deflect the light on the screen according to a saw-tooth form at the line frequency and similarly vibrator 7 must cause the light to traverse the screen linearly from top to bottom and rapidly back to the top in saw-tooth form at the picture frequency. The angle through which the mirror surfaces turn and hence the motion of light on the screen is assumed to be directly proportional to the current through the vibrators and to the voltage applied; hence in each case, the actuating voltage required is, as indicated, of the form Fig. 3*c*.

To better understand the specific circuits which follow, it is desirable first to consider broadly the functioning of the receiver and the cooperation of its parts, whereby the scanning operation at the receiver is synchronized with the transmitter and the picture correctly reproduces. Hence in Fig. 2 a diagram of the receiver is shown wherein unit blocks serve to indicate broadly the functions of the various receiver parts. The receiver illustrated is of the super-heterodyne type in that the incoming carrier wave and sidebands are collected by antenna structure 9, amplified by the ratio frequency amplifier 10, and applied to modulator 11, together with heterodyne energy from oscillator 12, to produce an intermediate frequency carrier and sidebands which are amplified by the intermediate frequency amplifier 13 and applied to detector 14. The detector 14 develops the vision frequencies, which represent detail in the picture, and also line and picture frequency impulses, which are to serve for synchronizing the scanning at the receiver with that at the transmitter and to "block out" illumination of the screen during each line retrace and each picture retrace interval. In order that the picture appearing on the screen shall be a "positive" and the impulse modulation of the carrier shall function for "block-out" of retraces, the proper poling of the output from 14 is applied to vision frequency amplifier 15 and the proper poling of the output of 15 as applied to the cathode ray tube grid 23 must be observed, so that as the cathode ray traces its pattern on the screen 25, the trace lines will be light or dark in accord with the corresponding line being traced at the transmitter, and the retrace lines will be black.

To make the case general, the cathode ray tube is shown as having magnetic control coils L_1, L_1, for the picture frequency and electrostatic control plates P_2, P_2, for the line frequency as was the case in Fig. 1*c*. The generator unit 18 serves to generate and supply saw-tooth voltage (labeled e_{3c}) of line frequency to the deflecting plates P_2, P_2 and the generator unit 21 here serves to cause saw-tooth current (i_{3c}) to flow in deflecting coils L_1, L_1 (i. e., it furnishes impulse voltage of form e_{3b} across these coils).

To control the frequency and timing (phase) of the outputs of units 18 and 21, the line frequency impulses and picture frequency impulses developed by detector 14 are also applied to filter units 16 and 19. Unit 19 is, for example, a low-pass filter suitable for passing the picture frequency impulse undistorted in wave form to unit 20 which is the picture impulse amplifier and which serves to apply the picture impulse properly poled and in adjusted amplitude as a control or synchronizing voltage to 21. Similarly, unit 16 is, for example, a band-pass filter to pass the line impulse to amplifier 17 which in turn serves to apply the line impulses properly poled and adjusted in amplitude as a control or synchronizing voltage to 18.

The arrows in the lines connecting units 16, 17 and 18, and similarly units 19, 20, 21, indicate that these are one-way circuits and that no voltage from units 18 and 21 is to pass in the opposite direction so that these generators in themselves shall not affect each other nor shall they react back on the detector 14 and hence on the amplifier 15 and the cathode ray tube grid 23.

The wave form of the synchronizing impulses supplied by 14 to units 16 and 19 is similar to that shown in Fig. 8*b* so that this graph may be taken as the form of impulse from 14 applied to control generator 18. Thus, as shown in Fig. 4*a*, during the time interval *t*, *u* a line *m* is being traced on the screen, and during the interval *u*, *t* the retrace *n* occurs (the ratio of time intervals being shown as 10:1). Similarly in Fig. 8*b* the control impulse endures for an interval *v*, *w* and is repeated after the trace interval *w*, *v*. This ratio of intervals is also shown as 10:1. Hence, if the impulse peak at *v*, occurs simultaneously with the end of the trace *u* in Fig. 4*a*, perfect synchronism is assured.

Remembering now that the impulse, Fig. 8*b*, is applied to the cathode ray tube grid 23 poled negative to cause the screen to darken simultaneously with its application to unit 16 for control, it will be evident that the screen will be dark during the retrace and bright during the trace as shown in Fig. 4*b*. If, however, generator 18 is producing a saw-tooth voltage as in Fig. 4*c* in which the ratio of trace to retrace is, say 7 to 3 as shown, and if synchronism is secured in that the points *u* of this voltage and *v* of the control impulse occur simultaneously, the result is that shown in Fig. 4*c* where the retrace is "blocked out" as long as the synchronizing impulse interval *v*, *w* endures. Here, however, the transmitter's line trace starts at *w* which is prior to the cathode ray beam having reached the left edge of the picture so that in effect the left side of the picture is "folded under". Other relations giving improper synchronism will be seen to be possible depending upon the relative phase of the synchronizing impulses and the relative ratios of trace to retrace time between the transmitter's scanning and the receiver's scanning processes. Hence for synchronism it is important in order that no part of the transmitted picture be lost, that the trace to retrace ratio of units 18 and 21 be as large or larger than that of the transmitted picture, and that the scannings correspond in phase in order that each line of the cathode ray tube screen starts with the corresponding line of the transmitted picture and that the retraces correspond so that retraces will be blocked out as shown in Fig. 4*b*.

If generator 18 produces a voltage only approximating the required voltage e_{3c} then it is important that the trace *m* part of the cycle should be linear but the shape of retrace *n* is unimportant so long as its time interval is held sufficiently short. Non-linearity in the line traces would result in the traces (*m* in Fig. 4) being curved and the picture detail would appear crowded together in some places and too widely spaced in others. The illustration is more easily given when non-linearity exists in the picture trace, as shown in Figs. 5*a* to 5*f* inclusive. Thus in Fig. 5*a* the wave-form shown for the picture frequency is that of Fig. 3*c* and the proper uniform spacing of the picture lines which results are shown in the first corresponding pattern Fig. 5*b*. The second pattern Fig. 5*c* indicates how the retraces are absent when proper synchronization of the picture frequency is achieved and "block-out" occurs.

Fig. 5*d* indicates that the saw-tooth current from generator 21 is of exponential form in both trace and retrace and the subsequent crowding of the lines at the bottom of the picture is shown in pattern Fig. 5*e*. With correct synchronization the retrace lines are blocked out as shown in pattern Fig. 5*f*.

It will be clear then that rigid requirements of design are imposed on generator units 18 and 21 of Fig. 2, in that they must supply saw-tooth voltage or current as the case requires having good linearity in the trace, adequate ratio of trace to retrace time, and proper response to synchronizing control voltages. Furthermore, the units 16 and 17 for the line control and 19 and 20 for the picture control must fulfill two functions: (*a*) apply the synchronizing impulse undistorted and in proper amplitude and phase to units 18 and 21, to effect synchronism; and (*b*) prevent reactions between these units and the rest of the system.

In the circuits which follow, fundamental circuits are first illustrated and specific circuits which perform the fundamental functions in a preferred manner are then given. It will appear that the units 16, 17, 19 and 20, Fig. 2, may be dispensed with, in part or in whole, where the design of the units 18 and 21 is such as to render their assistance unnecessary.

In Figs. 6*a* to 6*g*, a number of fundamental circuits are shown for producing current and voltage wave forms related to the saw-tooth derivative series. The circuits of Figs. 6*a*, *b* and *c* will be termed the R, C, type in that the desired wave form results from the charge and discharge of a condenser through resistance. The circuits of Figs. 6*d*, *e*, *f*, and *g*, are termed the L/R type in that the wave form results from the flow of current through an inductance as affected by resistance.

In the modification of Fig. 6*a*, a pendulum S periodically short circuits a capacity C through resistance *r* for a brief interval of time during each swing to the left, owing to closure of switch *g*. S is assumed to be actuated by some mechanism, as for example the usual clock escapement, so that the frequency of recurring short circuits is here determined by S. For the values which follow, the voltage across C relative to ground and the current through C are to a close approximation as shown in Figs. 7*a* and 7*b*, respectively.

E=300 volts, R=0.1 megohm, *r*=5000 ohms,

C=0.008 μf., ratio of trace to retrace=*b'*=10:1,

f=2250 cycles per second.

During each interval that the contacts of switch W are open, the condenser C is exponentially charged from source E through resistance R at a rate determined by the time constant of the circuit which depends on the product of R and C. During the retrace, that is, while the contacts of switch *g* are closed by swinging of the pendulum to the left, the condenser C discharges through the resistance *r* at a rate depending upon the product of *r* and C. The effect of the path through R on the rate of discharge condenser C can be neglected since R is large compared with *r*. The current through C, Fig. 7*b*, is the mathematical derivative of the voltage, Fig. 7*a*. It will be noted that the exponential saw-tooth voltage of Fig. 7*a* approximates the ideal form, Fig. 3*c*, and that the exponential impulse, Fig. 7*b*, approximates the ideal form, Fig. 3*b*.

The analogous case for an inductance is given in Fig. 6*d*, and the constants of the circuits, listed below, may be so chosen that the same curves of Fig. 7 represent the resulting wave forms; Fig. 7*a* in this case being the current through the inductance L and Fig. 7*b* being the voltage across the inductance. In the circuit of Fig. 6*b*, the battery E supplies current through *r*, L and O during the trace part of the cycle. The pendulum is here labeled O to indicate that it is an "opening" device instead of the "shorting device" of Fig. 4*a*. The contact to O is closed except during a brief interval during the end of the swing of O to the right. The circuit constants mentioned to satisfy Fig. 7, are

E=300 volts, L=4 *h*,

r=5000 ohms, R=100,000 ohms,

b'=10:1,

f=2250.

The current through L increases slowly and exponentially during the trace part of the cycle according to the time constant L/r. During the retrace the current falls rapidly and exponentially according to the time constant L/R. It will be noted that during the retrace the part of the circuit which includes E and *r* can be neglected (i. e., considered as of zero resistance) since R is large compared with *r*. The error in making this assumption is very small. The voltage across the coil is in this case the mathematical derivative of the current through the inductance and is as shown in Fig. 7*b*.

In the R, C case Fig. 6*a*, if circuit conditions permit values of R and C to be chosen so that operation occurs over only a small part of the exponential curve for the trace then the trace will be sufficiently linear to serve as a saw-tooth wave form for scanning.

Similarly, if L and *r* in Fig. 6*b* are chosen so that operation occurs over only a small part of the exponential trace (i. e., L/r is large) the resulting current wave form may be acceptable for scanning in television.

The exponentiality of retrace in both cases is unimportant but the time of the retrace interval is quite important. The frequency in each case is determined by the periodicity of the pendulum, and the ratio of trace to retrace is obviously determined by the ratio of the time that the contact to the pendulum is closed to the time it is open.

In Fig. 6*b*, the same elements of the R, C type circuit are present with the exception that S in this case is a shorting device which acts to short circuit C through r when the voltage across C has reached a predetermined maximum value. Assuming that the device S when closed (conductive) has no resistance and has infinite resistance when open (non-conductive) the same wave forms of voltage and current as shown by Fig. 7 result here if all circuit constants are the same as in Fig. 6*a* and if the device S closes when the value of voltage across C reaches a maximum of 150 volts, (i. e., when conversely the voltage between ground and point X has fallen to 150 volts) and opens when the voltage across C has fallen to 50 volts. A typical "relaxation" oscillator is this circuit in which S is a gaseous discharge tube such as a "Thyratron".

In practice the operating voltages of S may be controlled and when once they are fixed the fundamental frequency of the circuit can be readily set by adjusting either C or R, or both. Also, r affects frequency as shown by the equation for the generated frequency given below.

$$(1)\qquad f=\frac{1}{C\left(R\log\frac{V_1}{V_2}+r\log\frac{E-V_2}{E-V_1}\right)}$$

Where: f =frequency in cycles per second
C =capacitance in farads
V_1=maximum in volts developed across R
V_2=minimum in volts developed across R
E =maximum available battery voltage.

For a given adjustment of S the amplitude of saw-tooth voltage developed across C is independent of frequency.

In the analogous L/R type of circuit, Fig. 6*e*, the device O is substituted for the pendulum of O of Fig. 6*d* and is assumed to be a device normally closed or conductive and of zero resistance when closed, until the current through it reaches a predetermined maximum value at which instant it opens to become non-conductive. If the conditions are prescribed that O is conductive for all currents less than 30 milliamperes but non-conductive for currents exceeding this value, then with the remaining circuit constants as given for Fig. 6*d*, the wave forms of Fig. 7 again apply; Fig. 7*a* representing the current through L and Fig. 7*b* the voltage across L. In practice, if the adjustment of O remains unchanged, the frequency can be controlled primarily by changing r or L, or both. The equation for frequency is as given below, and again for a fixed condition of O, the frequency can be varied without changing the amplitude or output current through L.

$$(2)\qquad f=\frac{rR}{L\left(r\log\frac{I_1}{I_2}+R\log\frac{I-I_2}{I-I_1}\right)}$$

Where: f =frequency in cycles
L =inductance in henries
I_1 =maximum current that flows through L, in amperes
I_2 =minimum current that flows through L, in amperes
I =maximum current that can flow through

$$L=\frac{E}{r}.$$

In part, many of the circuits which follow relate to apparatus and arrangements which serve as the device S in R, C type circuits and as the device O in the L/R type circuits. Furthermore, synchronization is generally effected in connection with the controlling of S or O as the case may be, as will appear later. For the present, however, attention is directed to those parts of the circuits which control the trace of the cycle. Thus in Fig. 6*c* the device H replaces R of the preceding R, C circuits, and in the simple form illustrated is a two-element vacuum tube having the cathode temperature adjusted (adjustment not shown) to give limited electron emission, so that current through the tube is the same throughout a wide range of voltage across it. The tube is therefore a constant current device and the charging of C through H, during the trace of the saw-tooth voltage cycle is therefore linear with time as desired. For the circuit constants given below, the voltage across H (which is also that across C alone plus a direct current component) is as shown in Fig. 8*a* and the current through C is as shown in Fig. 8*b* which is the mathematical derivative of Fig. 8*a*:

E=300 volts
C=.008 μf.
r =5000 ohms
i =1.9 milliamperes
f =2250 cycles
b'=10:1

Here the approach to the ideal form of Fig. 3*c* is all than can be desired since the trace is linear and the form of the retrace is immaterial providing its time interval is sufficiently brief. The frequency is:

$$(3)\qquad f=\frac{i}{C\left(V_1-V_2+ir\log\frac{E-V_2}{E-V_1}\right)}$$

Where: i=constant current through H in amperes and other symbols have same significance as in Formulas 1 and 2.

Since the current through H is a constant steady value of direct current, and by Kirchoff's law, the sum of the currents flowing to the point X must be zero, the wave form of current through S is identical with that through C with the addition of a direct current component. The voltage across a resistor inserted anywhere in this loop (as for example the voltage across r) will be of an impulse wave form, Fig. 8*b*. This circuit is therefore a source of current or voltages of saw-tooth or impulse wave form or of a combination of the two.

Since the condenser C passes no direct current it is immaterial as to whether its lower terminal is connected at point y as shown or whether this terminal is connected to ground G or to some intermediate point on the battery E. The action is entirely the same as to the current through C and the alternating voltage across it; a change in only the direct current voltage component across C results. Actually the curve, Fig. 8*a*, is the voltage between X and G and is obviously the voltage across C plus E or simply the voltage across H.

An advantage of returning C to the plus terminal of E results when the voltage source E has appreciable resistance since then E is located in the constant current branch of the circuit and no impulse current flows through it. Hence any reaction through the power supply source is avoided in practical circuit arrangements. When returned to point G it is more correct to say that C is rapidly charged when S operates and that C discharges at a constant current rate through H. There is no reversal, however, of the saw-tooth voltage generated.

In the R, C type circuit just described a constant-current device served to linearize the voltage trace. In an analogous manner a constant voltage device will serve to linearize the current trace in the L/R type generator. Thus in Fig. 6e the trace is exponential due to the fact that as the current increases through L, it likewise increases through r and the voltage drop across r prevents the voltage across L remaining constant during the trace. If Fig. 3c is the current through L then the voltage across L as shown by Fig. 3b must be constant during the linear trace. Clearly if r were zero (and r includes any resistance present in the inductance L) then the voltage across L would remain constant during the current trace when O is closed. Under such conditions Fig. 8a represents the current through L and Fig. 8b the voltage across L for the constants which follow:

E = 200 volts
L = 4 henries
R = 100,000 ohms
r = 2250 ohms
b' = 10:1

The frequency is determined by:

$$f=\frac{E}{L\left(I_1-I_2+\frac{E}{R}\log\frac{I_1}{I_2}\right)} \quad (4)$$

Where: E = constant voltage in series with L, and other symbols have same significance as in the preceding formulas.

To make r zero a negative resistance $-r$ may be introduced as is illustrated in Fig. 6f.

The equivalent of introducing a negative resistance $-r$ to maintain constant the voltage across L during the trace is shown in Fig. 6g where a generator e_{3c} of saw-tooth voltage properly poled and adjusted in amplitude is introduced in series with r and L. If the resultant current through L is of saw-tooth wave form then the voltage drop across r will be of saw-tooth wave form, and hence the insertion of generator e_{3c} will compensate for the voltage drop across r to maintain the voltage across L constant during the trace. Fig. 8a represents the current through L and Fig. 8b the voltage across L for this figure. Also the voltage across O is of impulse form since the sum of the voltage drops across r, L, R and e_{3c} must add up to the constant direct current voltage E.

The L/R circuit may be developed as an amplifier of an R, C generator's output to produce saw-tooth current through scanning inductances. Or it may be developed as a self-sustaining generator as will appear later. For various economic reasons in construction and operation of cathode ray tubes as television projectors, it appears that magnetic control of scanning may be favored. Hence the precise production and control of saw-tooth current through an inductance is required.

It has been pointed out that the R, C generator may be employed to provide saw-tooth, impulse, or a combined saw-tooth impulse voltage. In Fig. 9a the two wave forms of Fig. 8, both now understood to be voltages, are shown first separately and then combined to give a resultant saw-tooth plus impulse voltage wave form. Such a resultant voltage is, for example, obtainable between points Y and Z of Fig. 6c. If, for example, this voltage is applied across deflecting plates of the cathode ray tube for picture frequency spanning, (with a saw-tooth form of control simultaneously operating for the line scanning) the pattern on the screen will be as shown in Fig. 9b. If the transmitter's retrace endures for a time interval only one-half as long as that of the impulse component of this scanning wave, the picture retrace block-out will appear as shown in Fig. 9c. This blocks out that part of the picture retrace which lies across the field to be viewed and throws that part of the retrace which was not blocked out above the field of view. These lines showing above the field of view constitute, of course, the top lines of the picture which now must be sacrificed and may be obscured by an opaque mat (frame) which will present only the field of view to the observer. In effect, however, the retrace time has been shortened.

In practice, it is generally more difficult to obtain a relatively sort retrace time in the case of high frequencies such as the line frequency. Hence by employing the combined saw-tooth and impulse for the line frequency voltage (this illustration being for the case of electrostatic scanning) the folded under-part of the lines (as t, w in Fig. 4a can be thrown to the left of the picture, and while this adds nothing of value to the left side of the image it does avoid the disturbing effect of the folded-under lines giving a ghost picture. A proper proportioning of the relative amplitude of the two forms to be combined is important for correct results.

A perfect saw-tooth wave form having zero retrace time involves frequencies extending to infinity in the harmonic composition of the wave and it would be impossible to provide circuits for their use. It can, however, be shown that the plot of the summation of the first ten harmonics of the infinite Fourier series required to represent a saw-tooth wave having a 10:1 ratio of trace to retrace, Fig. 3c, is a curve very closely approximating the ideal. Similarly, it can be shown that the plot of the summation of the first ten harmonics of the infinite Fourier series required to represent a saw-tooth wave having zero retrace time does not, in comparison give a close approximation of its ideal.

Nevertheless, while recognizing this limitation, it is, at times, easier to generate a saw-tooth wave with a retrace interval which is too great and then improve this retrace time. The combination of an impulse and a saw-tooth having an exponential retrace (of form as in Fig. 8a) is given in Fig. 10. Here the resultant wave form is a perfect saw-tooth with zero retrace time. The form of impulse which is here used to combine with the Fig. 8a form is not that of Fig. 8b but can be derived, to a close approximation, from Fig. 8b by rectification.

An equally important need for the combined saw-tooth and impulse wave form is required when the inductance, through which saw-tooth current is to flow, has resistance in series with it which is nearly always the case. This is shown for the ideal case in Fig. 11a, where the load circuit is indicated as L and R in series. The current is to be of the form of Fig. 3c and hence the voltage e_R is indicated as of that form. The voltage e_L is accordingly of the form of Fig. 3b as illustrated, and the resultant voltage which must be applied across this load is the wave form

e shown. The resultant voltage e is here obtained by arbitrarily adding the instantaneous values of these two forms. Since the resultant wave form of e depends on the relative values of L and R, a second showing of the resultant wave form labeled e' is indicated in which the impulse voltage across L is taken as one-third of its value in the first case. In other words, the inductance L was taken as being smaller in value relative to R, the current remaining the same, in deriving the voltage wave form e'.

The entirely similar case where the current trace is linear but the retrace is exponential as in Fig. 8, is shown in Fig. 11*b* and two cases of the resultant voltage wave form required are shown as e and e' for this figure.

Where a very large value of R is employed in series with L, the voltage applied to cause a saw-tooth current to flow will necessarily reduce to simply the saw-tooth wave form, while in the other extreme where the series resistance is negligible the voltage wave form necessary to cause a saw-tooth current will reduce to simply impulse wave form.

Frequently as will be seen in circuits which follow, it is desirable to have capacity in series with the inductance to prevent any direct current flow through the scanning coils. Such a load circuit and its performance are illustrated in Fig. 11*c*. For a current of form Fig. 3*c* to flow in this circuit, the voltage e will be a resultant of Figs. 3*b*, 3*c* and 3*d*, each component being properly adjusted in amplitude to fit the load circuits.

In the case of high (line) frequency scanning the capacity C, of Fig. 11*c*, can generally be made sufficiently large so that its reactance is negligible. Hence a parabolic impulse voltage wave form Fig. 3*d* need not be included as a necessary component of e, and the required voltage wave form reduces to that shown as e'. Fig. 11*b*.

The current through the scanning coils can, of course, be made very large in the type of load circuit of Fig. 11*c* by having L and C resonant at, or near, the fundamental frequency of the wave form. Such a design, however, materially attenuates the harmonic components and generally results in requiring that R be made large, which again reduces the current amplitude as the saw-tooth current wave form is improved.

In the case of low (picture) frequency scanning L is generally so small that its reactance is negligible. Hence a voltage of impulse wave form, Fig. 3*b*, need not be included as a necessary component of e. It is, however, almost impossible to make C large enough in this case to pass the fundamental components of the very low frequency wave form, so that its reactance is usually appreciable for picture frequency scanning. When simply a saw-tooth voltage wave form is employed, it will be noted when viewing the scanning pattern on the fluorescent screen, under this condition, that the wave form appears approximately exponential. To counteract this effect of exponentiality in the picture trace it is necessary to introduce a compensating wave form, Fig. 3*d*, of proper amplitude, in combination with the form, Fig. 3*c*, for low frequency scanning. Thus in Fig. 11*c* the first cycle shown is of form Fig. 3*c*, indicated as the wave form of voltage e applied. The current, and hence the voltage e_R, Fig. 11*c*, is shown as having approximately exponential trace and retrace. The difference in voltage between e and e_r is e_c which is of the form Fig. 3*d* (parabolic impulse) as shown of small amplitude in Fig. 11*c*.

Mathematically, it can be shown that this wave form is composed primarily of the low frequency fundamental and the lower harmonics; that is the amplitude of the harmonics decreases rapidly with frequency and hence the observation that discrimination against the low frequency components tends to make the saw-tooth wave form appear exponential is confirmed.

The simplest arrangement of saw-tooth current generator which satisfies the requirements of Fig. 6*d* is a vibrator or buzzer such as that shown in Fig. 12. Starting with the closing of the contact O the voltage across L is constant except for voltage drop due to resistance in the windings and hence the current rises exponentially until the magnetic flux developed by coil L opens the contact O. The circuit resistance then being very high, the current falls rapidly, the voltage across L becoming a very high impulse peak. This is the well known high voltage peak which occurs at the "break", as in a "make" and "break" ignition system. The wave-form of voltage, except insofar as it is impaired by sparking at the contacts, will be of the form shown in Fig. 7*b* and the current as in Fig. 7*a*. Forgetting for the moment that it is actually the magnetic flux which opens the contact, it is clear that O is a device which is conductive until the current through it reaches a predetermined maximum at which point it opens. Hence the arrangement of Fig. 6*d* is satisfied by this circuit.

A vacuum tube may be utilized in two fundamentally different ways to give saw-tooth current through an inductance (this statement being made without regard as to whether or not the voltage control applied to the grid is from a separate source or the result of a feedback). The tube may be employed as a linear amplifier to repeat the voltage applied to the control grid into the plate circuit as illustrated in our copending application Serial No. 747,068, filed Oct. 5, 1934, Patent No. 2,052,183, granted August 25, 1936, or the tube may be caused to operate as an "opening device" going beyond the limits of linearity as will be explained. In using the tube as a linear amplifier, an arrangement not given in the mentioned copending application is that of Fig. 13*a*. Here vacuum tube **26** has voltage of impulse wave form e_g applied between its control grid and cathode. In the plate circuit a filter network (band-pass) comprising elements **27**, **28**, **29**, **30**, **31**, **32**, **33** and the scanning inductance L_{sc}, constitutes a resistance load for the band of frequencies necessary to simulate the saw-tooth wave form being considered. The voltage e_g applied between control grid and cathode is illustrated as being of impulse wave form corresponding to Fig. 3*b*. Hence since the load is resistive (or what is the same thing, the output voltage is a replica of the input voltage) the output voltage across L_{sc} will be of impulse wave form and the current therein will be of saw-tooth form, Fig. 3*c*, according to the derivative series.

Consider now Fig. 13*b* in which tube **26** is again excited by an impulse wave form e_g. Here the load is inductive. Coil **34** is assumed to be large compared with the scanning inductance L_{sc} and capacity **35** is large (low reactance to the scanning frequency) so that L_{sc} is essentially the plate circuit load. If under these conditions tube **26** is operated as an amplifier over the linear part of its characteristic then the current will not be saw-tooth in form through L_{sc}, with the impulse excitation shown, since a voltage drop occurs due to the plate cathode resistance of tube 26. If, however, tube 26 is operated as an opening device to simulate Fig. 6d, the resulting current through L_{sc} can be made of good saw-tooth form. This can be done by poling the impulse voltage e_g applied to the grid of 26 so that the peaks as applied to this grid are negative. Here the selection of a tube which has low plate-cathode resistance when the grid bias is small and which passes no current when a large negative bias is employed, is important. It will be clear under such conditions that tube 26 serves to close the plate circuit during the trace part of the cycle and opens it briefly during the negative impulse peak for the retrace. The current through L_{sc} under such conditions will be of saw-tooth form. The traces will be exponential approaching linearity to an extent dependent upon the reduction in tube resistance and output circuit resistance.

It was pointed out in Fig. 11 that where saw-tooth current is to flow through a load of resistance and inductance in series, the applied voltage should be a resultant of saw-tooth and impulse components properly proportioned. Likewise in Figs. 6f and 6g, it was shown that the voltage drop across r, during the trace, which operates against linearity, can be compensated for by a negative resistance $(-r)$, or an introduced saw-tooth voltage, to compensate for the drop across the circuit resistance r when saw-tooth current flows. Hence coming to Fig. 13c it will be clear that by using a combined impulse and saw-tooth wave form (as e_g there illustrated) for the grid control voltage, current of saw-tooth wave form in the plate circuit can more readily be obtained. Here, in order to avoid a direct current component through the scanning coils a transformer 36, 37 is employed to couple L_{sc} in the plate circuit as an alternative of the capacity coupled arrangement of Fig. 13b. The effective circuit resistance is represented by resistor 38. If tube 26 is operated as a linear amplifier a fixed value of plate-cathode resistance must be considered in series with resistance 38 and the inductive load. Under such conditions the saw-tooth component required will be relatively large and the poling of voltage e_g is immaterial.

If, however, it is desired to operate tube 26 as an opening device, it is important that the impulse peaks be poled to be negative as applied to the grid of tube 26. For such non-linear operation of tube 26 this tube opens the plate circuit during the retrace when the grid is highly negative and during the trace the saw-tooth component acts to compensate for the voltage drop due to tube and circuit resistance thereby holding the voltage across transformer 36, 37 constant and hence assuring good linearity of current traces through L_{sc}.

In our Patent No. 2,052,183 various resistance-capacity type circuits for supplying saw-tooth and impulse voltage or their combination have been illustrated. One of these forms is here shown in Fig. 14 with the modification that the impulse voltage is directly used to cause saw-tooth current to flow through inductance. Thus voltage E charges capacity C substantially linearly with time due to a resistor or constant current device H, such as a suitably arranged space discharge tube, which controls the frequency generated. Tube S acts as the short-circuiting device to discharge C when the voltage across C has reached a predetermined value. The action of S is rendered effective by regeneration due to feedback transformer T, damped by resistor 39 to prevent spurious oscillations. The load circuit is of the form of the filter of Fig. 13a, and hence is similarly labeled. The current through the shorting tube S is of impulse wave form, the load being resistive for the band of frequencies to be passed, so that the voltage across the filter input and output L_{sc} is of impulse wave form. Therefore, the current (see derivative series Fig. 3) through L_{sc} will be of saw-tooth form since the voltage across L_{sc} is of impulse wave-form.

Fig. 15 shows a complete circuit for carrying out the arrangement of Fig. 13b, the impulse wave-form generator being one which has been illustrated and described in our Patent No. 2,052,183. Voltage source E charges condenser C through constant current device, tube H; the value of charging current, and hence the frequency, being controlled by the grid tap f which sets the bias on the control grid of H. Short circuiting tube S, regenerated by the reversing tube Rv acts to short circuit condenser C when its potential has reached a predetermined value which will cause current to start flowing between plate and cathode of tube S. The current through tube S and hence through its plate resistor 40 is of impulse wave form as shown, for example in Fig. 8b, and this voltage is applied via capacity 41 and resistor 42 to the control grid of tube 26. The poling of this impulse voltage is such that negative peaks are applied to the grid of tube 26. The output of tube 26 is similar to that of Fig. 13b and hence the elements are similarly labeled. It will be clear that a current of saw-tooth wave form will flow in scanning inductance L_{sc}. Whether or not the current wave form will be sufficiently linear depends, of course, on the choice of tube 26 and the circuit constants.

In Fig. 16 a simplification of Fig. 15 is shown which in practice gives a current of quite good saw-tooth wave form through scanning inductance L_{sc}. Here the feed-back or reversing tube Rv fulfills also the function of an output tube. The voltage source E charges capacity C through constant current device H, which controls the generated frequency. The shorting of condenser C for the retrace part of the cycle is accomplished by tube S regenerated by tube Rv. Since the current through tube S is of impulse wave form, the voltage across resistor 40 applied to the grid of tube Rv is of impulse wave form with the peaks poled negatively. The output circuit of tube Rv is similar to that of Figs. 13b and 15. The current through L_{sc} is of saw-tooth form and the voltage across L_{cs} is of impulse form and properly poled so that when applied to the grid of tube S over connection 57 the impulse peaks are positive to regenerate tube S and accelerate the shorting of capacity C.

In circuits 14, 15 and 16 the points for synchronization and the proper poling of synchronizing impulses (as from the units 17 or 20, Fig. 2, as the case may be) are indicated by the labels "−synch." and "+synch.". The matter of synchronism is considered at length in our mentioned Patent No. 2,052,183. Tubes with synchronizing grids may be employed in the position of S and Rv in these and the following circuits.

The circuits of Figs. 15 and 16, are as noted, arranged to secure either the operation of Fig. 6d or that of Fig. 13b in that a separate generator source of voltage of impulse wave form is provided. The circuit of Fig. 17 is particularly designed to function according to the principles of Fig. 6e. Here tube 26 acts as the opening device when the current in its plate circuit has reached a predetermined maximum. If current of saw-tooth wave form flows in the plate circuit of tube 26, the voltage across resistance 58 will be of saw-tooth form. No current flows between plate and cathode of tube S until a predetermined voltage across resistor 58 is developed. When the voltage across 58 has reached a value sufficient to cause current to flow in tube S, a negative voltage is developed at the grid of tube Rv, which tube in turn applies a positive voltage to the grid of S. Tube S is therefore regenerated by tube Rv to cause tube S rapidly to short circuit resistor 58. Simultaneously a negative impulse from the plate of tube S is applied to the control grid of tube 26, via the grid blocking condenser 59, and leak resistor 60. Tube 26 thus automatically opens the circuit when the current has reached a predetermined maximum value.

An alternative way of picturing the circuit's operation is to consider tubes S and Rv as a source of impulse voltage properly poled and applied to the grid of tube 26, to carry out the requirements of Fig. 13b. The impulse generated is, however, controlled by the rise in current through resistor 58. Resistor 58 is made variable to control the generated frequency. During the trace part of the cycle when tube 26 is conductive, the time constant is determined by the effective inductance of 36 and resistor 58 plus the remaining circuit resistance. During the retrace the time required for the current to fall depends upon how high the resistance in the plate circuit remains when the bias on the grid of 26 is made highly negative. This circuit then is strictly an L/R type and increasing resistor 58 serves to increase the generated frequency. The current wave form is an exponential saw-tooth of the form Fig. 7a but can be made to approach very good linearity in the trace by careful design.

The circuit of Fig. 18 is an L/R type generator operating in accordance with the principles of Figs. 6f and 6g. As in previous figures the scanning coils L_{sc} are coupled into the circuit through transformer 36, 37, in part to eliminate the direct current component, and to secure an impedance match for best performance by introducing an effective inductance into the plate circuit of tube 26 to give optimum results. The circuit provides saw-tooth current of quite good wave form, slightly exponential as to traces. It is clear from Fig. 11 and its exposition, that the voltage across coil 36 is of impulse form, that across resistor 58 is of saw-tooth form, and the resultant as applied between grid and cathode of tube Rv via capacity 61 and potentiometer 62 is of combined saw-tooth and impulse wave form.

The tube Rv is a linear voltage amplifier for repeating the combined impulse and saw-tooth voltage in reversed polarity between the grid and cathode of tube 26 via capacity 59 and resistor 60. The poling of the voltage wave form of impulse plus saw-tooth is such that the impulse voltage peaks are negative as applied to the grid of tube 26 to "open" its space path for the retrace part of the cycle. Adjustable resistor 58 controls the rate at which the current rises during the trace part of the cycle and hence serves as a frequency control; an increase in the resistance corresponding to an increase in frequency.

Tube Rv not only applies the negative impulse to the grid of tube 26 to cause it to "open", but during the trace part of the cycle it repeats the saw-tooth voltage component so that the grid of tube 26 grows more positive as the trace part of the cycle progresses, i. e., the resistance of the plate-cathode of tube 26 fails to afford the compensation suggested by the generator e_{3c} of Fig. 6g or the negative resistance $(-r)$ of Fig. 6f. In practice care must be taken with this circuit to avoid overloading the grid of tube Rv.

Instead of a reversing tube Rv for the feedback as in Fig. 18, a magnetic feedback may be utilized as shown by the addition of a third coil 64, Fig. 19, to the transformer 36, 37. Assuming the result that current of saw-tooth form flows in coil 36, the voltage across the coil is of impulse wave form and hence, that across coil 64 is likewise of impulse wave form poled to apply the peaks negative to the grid of tube 26. Only the impulse and not the saw-tooth component is applied back to the grid of tube 26. In practice the frequency is controllable by either an adjustable resistor 65 in the plate circuit, Fig. 19a, or by resistor 66 in the grid circuit. When one of these resistors is used, the other may be omitted. In either case, an increase of resistance corresponds to an increase of the frequency generated. In practice, a quite acceptable current of sawtooth wave form is obtained through the scanning coils L_{sc}.

The arrangement of Fig. 19b differs from that of Fig. 19a only in that resistor 67 is employed in the cathode branch common to both plate and grid circuits. Increase of resistor 67 corresponds to increase in generated frequency and in general the performance of the Fig. 19b circuit is slightly superior to that of Fig. 19a. The circuits of Fig. 19 are more effective for high (line) frequency than for low (picture) frequency scanning.

Various other arrangements of the circuits of Figs. 18 and 19 can be made to carry out the principles involved such, for example, as a combination arrangement of the two whereby a reversing tube will serve to perform a part of the feedback and a feedback coupling will serve to perform part of the feedback function.

In our mentioned Patent No. 2,052,183, arrangements were shown for exciting the grid of amplifier circuits with a voltage of combined saw-tooth plus impulse wave form. The amplifier circuits there employed were linear and current of saw-tooth wave form through inductance was obtained in the amplifier output circuit by employing considerable resistance in series with the inductance. The generating circuits there shown were of the resistance-capacity type and the poling of the impulse peaks as applied to the amplifier grid was unimportant and was, in fact, such that the impulse peaks were positive.

The three circuits of Figs. 20, 21, 22, likewise employ the resistance-capacity type of voltage wave form generators, arranged in what is herein termed for convenience, the inverted form. This arrangement permits an impulse plus saw-tooth combined voltage wave form to be applied to the grid of the following amplifier tube with the impulse peaks poled negative so that this amplifier tube may function according to the arrangement given and described for Fig. 13c. The poling of the wave form is important only when the tube is to operate beyond "cut-off" so that the plate circuit load may be primarily inductive.

Thus in the circuit of Fig. 20 battery E charges C through resistance R and resistance 68, R being adjustable to control the generated frequency. Tube S acts as the shorting device when the potential between its cathode and plate reaches a maximum value determined by the bias on its control grid. It has been shown in connection with the description of Fig. 6c that an impulse current circulates in the loop circuit 68, C and through space path of S. Hence the voltage drop across resistor 68 applied to the grid of tube Rv causes tube Rv to, in turn, apply a positive impulse peak to the grid of tube S, so that tube Rv acts as the reversing or feedback tube to regenerate tube S for rapid discharge of condenser C. The polarity of the impulse voltage developed across resistor 68 and the saw-tooth voltage developed across condenser C is reversed to that obtainable relative to ground across condenser C, for example, in Fig. 15. It follows then that the combined impulse plus saw-tooth voltage developed across resistor 68 and condenser C is applied to the grid of tube 26 through capacity 69 and potentiometer 70, with the poling such that the impulse peaks are negative as applied to the grid of tube 26.

The output circuit of tube 26 could, of course, be of the form shown as the output or plate circuit of Fig. 13b or 13c. In Fig. 20 the output arrangement comprises resistor 71, capacity 72, scanning inductance L_{sc} and resistor 73. A resistor 74 in the cathode path gives negative regeneration. This output arrangement is most effective for low (picture) frequencies. The negative regeneration element 74 has been found effective in maintaining good linearity of the saw-tooth current trace even when low frequency components are attenuated due to the reactance of capacity 72 (which should be as large a capacity as is feasible) and reaction through the power supply elements.

In the output circuit of Fig. 20, as shown (or with a different output as for example, that of either Figs. 13b and 13c), current of saw-tooth wave form flows in scanning coils L_{sc}. Where the grid voltage of tube 26 contains an impulse component which is large compared with the saw-tooth component, tube 26 will operate as an "opening" device and resistor 73 may be reduced in value or omitted. Tube 26 can, of course, be operated as a linear amplifier, resistor 73 being then relatively large. For this condition the saw-tooth component of the grid voltage would become predominant, and under these conditions the poling of the exciting wave becomes unimportant. The relative magnitudes of the saw-tooth and impulse voltage components as applied to the grid of tube 26 are determined by the choice of values for resistor 68 and capacity C.

In Fig. 21 the resistance-capacity type of generator employs a voltage source E charging capacity C through constant current tube H. Capacity C is shorted by tube S regenerated by tube Rv when the voltage across C has reached a predetermined maximum amplitude. This resistance-capacity type of generator is again of the so-called inverted form (as compared with that of Fig. 15 for example) in order that the voltage of combined impulse plus saw-tooth wave form as applied to the grid of tube 26 shall be properly poled so that tube 26 may operate as an "opening" device as described in connection with Fig. 20. Hence the cathode of device H is above ground potential, and in order that there shall be no relative changes at the generated frequency of voltage between screen grid and cathode, and between the control grid and cathode of tube H, the bias to the control grid, which determines the generated frequency, is furnished by the direct current voltage drop across potentiometer 79 and the direct current potential to the screen grid is through resistor 78. Capacity 77 connects the screen of tube H to its cathode and the time constant of the resistance-capacity branch 78, 77 is made to correspond to a frequency lower than the fundamental frequency generated, so that the voltage between screen and cathode remains constant. In a like manner the bias for the control grid of tube H may be secured by connecting its grid through a resistor to a tap on E, and providing a capacity path from control grid to cathode instead of employing 79 as shown. The only adverse criticism to such a connection is that the response of the circuit to any change of bias on the control grid for setting the generated frequency is sluggish, due to the time constant of the resistor-capacity circuit suggested, which may be made low.

It will be observed that the impulse voltage drop across resistor 76 is applied to the grid of tube Rv poled to make its grid, during the impulse peaks, negative with respect to its cathode, and that tube Rv in turn applies an impulse voltage to the grid of tube S poled to make its grid, during the impulse peaks, positive with respect to its cathode. Tube Rv thus regenerates S to expedite the shorting of condenser C during the retrace part of the cycle. The resultant impulse voltage across resistor 76 and saw-tooth voltage across condenser C are a combined impulse plus saw-tooth voltage properly poled to be applied to the grid of tube 26 through 69 and 70 so that the action from there on is like that already described for Fig. 20.

In Fig. 22, another arrangement is shown of a resistance-capacity generator inverted to give a properly poled voltage of combined impulse plus saw-tooth wave form applied to the grid of output tube 26. Here voltage source E charges C through resistor R (or other constant current device) and the short circuit for the retrace part of the cycle is accomplished by tube S regenerated by feedback transformer T instead of by a reversing vacuum tube. Resistor 39 (as in Fig. 14) damps the transformer T to prevent spurious oscillation which may occur due to the circuit constants and distributed capacities of T and S. A resultant voltage having an impulse component due to the voltage drop across resistor 75 and a saw-tooth component due to the voltage drop across condenser C is applied to the control grid of tube 26 through capacity 69 and potentiometer 70. Saw-tooth current flows in output scanning coils L_{sc} as discussed in connection with Fig. 20.

In the three circuits of Figs. 20, 21 and 22, the branch 69, 70 should be of high impedance to prevent its acting as an appreciable load on the generator part of the circuit, and it should provide good fidelity (i. e., a low time constant as determined by capacity 69 and resistor 70) to apply the generated voltage wave form undistorted to the grid of 26.

Referring to Fig. 23, the circuit there shown carries out the principles of Fig. 6d by substituting for the pendulum arrangement O there shown, a mechanical interrupter O controlled by a vacuum tube oscillator acting as the frequency determining source. With O closed the current through winding 36, and hence through scanning coils L_{sc} coupled thereto by winding 37, rises exponentially with time (the exponential approaching linearity as the resistance of the circuit approaches zero) for the trace part of the cycle. The retrace occurs when O is briefly opened during each cycle of the frequency generated by tube 80 when the current through polarized windings 81 is a maximum. The oscillating circuit for tube 80 is of a typical form comprising a tuned grid circuit and feedback winding in the plate circuit. The voltage developed in the plate circuit winding is applied to coil 81 through capacity 82. Many variations of the particular arrangement shown will occur to those skilled in the art. The particular form of the contact O may, for example, be of the vacuum tube type to reduce the effects of sparking at the contact.

In Fig. 24, an L/R type of saw-tooth current generator is shown which employs the negative resistance characteristic of the dynatron to effect its operation. Here tube 83 has a voltage source E applied between cathode and one grid acting as the anode. A direct current bias adjustment, labeled *f*, on the grid nearer the cathode serves to determine the slope of the negative resistance characteristic at which operation occurs and also to control the generated frequency. Scanning coil L_{sc} may be directly introduced in the plate circuit or coupled therein by transformer winding 36, 37 as shown. Resistor 84 represents the resistance introduced by 36, 37, and L_{sc} which would be made as low as possible. For good wave form of saw-tooth current through L_{sc} the distributed capacities related to winding 36, 37 and L_{sc} should be kept low. The control of frequency by adjustment of the negative bias at *f* is effective in increasing frequency as the bias is increased. Resistance introduced in the anode (screen) circuit also increases the generated frequency.

The arrangement of Fig. 24 is in practice an economical and efficient generator of current of saw-tooth wave form through the scanning inductances. It is particularly suited to the generation of high (line) frequencies. Synchronization can be achieved by applying the impulses of the synchronizing signal to frequency control grid.

It will be clear to those skilled in the art, that any of the generator units here shown may be substituted and co-ordinated to serve as the units 18 and 21 of Fig. 2 in a complete receiver and projector of television images.

We claim:

1. In an electric wave generator: a first vacuum tube having grid and plate circuits, means supplying direct current operating potentials to electrodes of said tube, said plate circuit containing inductance and a resistor in series, and means producing in said inductance a current of saw-tooth wave form having retrace intervals of short duration relative to the trace intervals, said means comprising, a connection shunting said resistor and containing the space path of a second vacuum tube arranged to pass current when the voltage across said resistor reaches a predetermined value, a capacitive coupling from the grid of the first tube to the plate of the second, and a third vacuum tube regeneratively coupling the input of said second tube to its output, whereby a negative potential is applied to the grid of the first tube from the plate of the second upon occurrence of said predetermined maximum voltage across said resistor thereby to accelerate retrace of said saw-tooth current.

2. In an electric wave generator adapted to provide current of saw-tooth wave form through inductance: a first vacuum tube and a second vacuum tube each having input and output elements, an output load for said first tube comprising inductance and a first resistance in series, means for coupling the output of said first tube to the input of the second tube, means including a second resistance and capacity coupling the output of the second tube to the input of the first tube to provide regenerative feedback in which the frequency determining elements are essentially said inductance and said first resistance whereby the voltage across said inductance is of impulse wave form and the current therein is essentially of saw-tooth wave form, and means for adjusting said first resistance to control the generated frequency.

3. An electric wave generator adapted to provide current of saw-tooth wave form for passage through a scanning inductance, comprising a normally conductive vacuum tube, input and output circuits therefor, a three-winding transformer having a pair of its windings included respectively in said input and output circuits, said vacuum tube being actuated by current in said circuits to periodically open said output circuit for only a small fraction of each cycle and the winding polarities being such as to provide regeneration between said input and output circuits, a variable resistance included in at least one of said circuits, said resistance and the inductance of said transformer winding in the last said circuit being proportioned to determine the periodicity of the generated wave, means for adjusting said resistance to control said periodicity and means for coupling said third winding to the scanning inductance.

4. In an electric wave generator adapted to provide a current of saw-tooth wave form through a scanning inductance, a circuit effectively including said scanning inductance and comprising, in series, inductance means, resistance means, a normally fully conductive circuit controlling device, and a source of operating voltage for said circuit, means responsive to operating conditions in said circuit for periodically rendering said device substantially completely non-conductive for only a small fraction of each cycle and means for adjusting said resistance means to control the periodicity of said generator.

5. In an electric wave generator adapted to provide a current of saw-tooth wave form through a scanning inductance, a circuit effectively including said scanning inductance and comprising, in series, inductance means, resistance means, a normally fully conductive circuit controlling device comprising the space-current path of a vacuum tube, and a source of operating voltage for said circuit, means responsive to a predetermined current through said circuit for periodically rendering said device substantially completely non-conductive for only a small fraction of each cycle and means for adjusting said resistance means to control the periodicity of said generator.

6. In an electric wave generator adapted to provide a current of saw-tooth wave form through a scanning inductance, a circuit effectively including said scanning inductance and comprising, in series, inductance means, resistance means, a normally fully conductive circuit controlling device including the space-current path of a vacuum tube, and a source of operating voltage for said circuit, means responsive to operating conditions in said circuit for periodically rendering said device substantially completely non-conductive for only a small fraction of each cycle and means for adjusting said resistance means to control the periodicity of said generator.

7. In an electric wave generator adapted to provide a current of saw-tooth wave form through a scanning inductance, a circuit effectively including said scanning inductance and comprising,

in series, inductance means, resistance means, a normally fully conductive circuit controlling device including the space-current path of a vacuum tube, and a source of operating voltage for said circuit, vacuum tube means responsive to operating conditions in said circuit for periodically rendering said device substantially completely non-conductive for only a small fraction of each cycle and means for adjusting said resistance means to control the periodicity of said generator.

8. In an electric wave generator adapted to provide a current of saw-tooth wave form through a scanning inductance, a circuit effectively including said scanning inductance and comprising, in series, inductance means, resistance means, a normally fully conductive circuit controlling device, and a source of operating voltage for said circuit, and means responsive to operating conditions in said circuit for periodically rendering said device substantially completely non-conductive for only a small fraction of each cycle, said inductance means and resistance means being so proportioned as to comprise a time-constant circuit which determines the periodicity of said generator.

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