

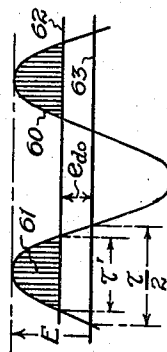
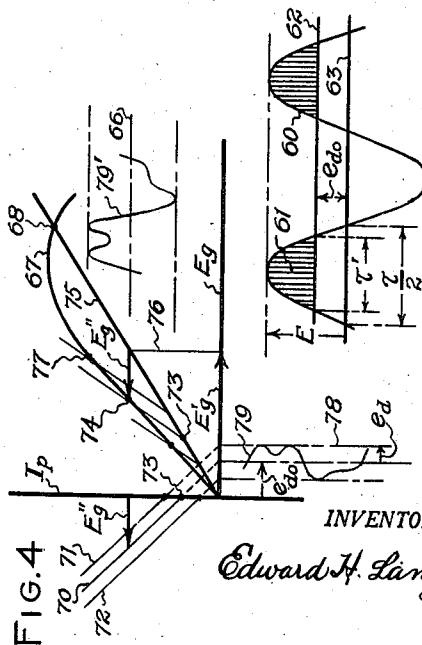
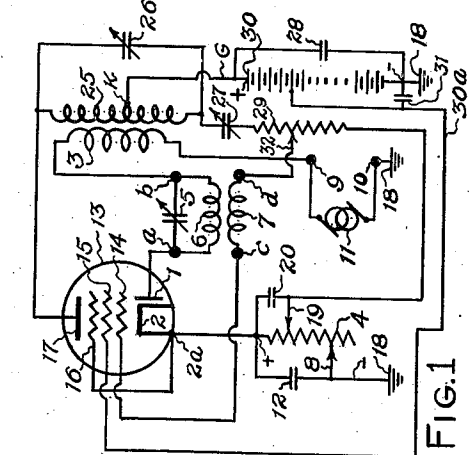
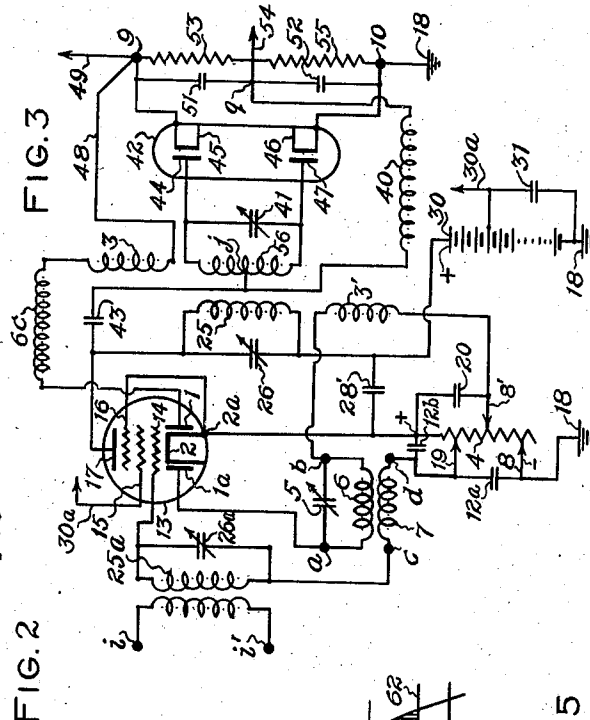
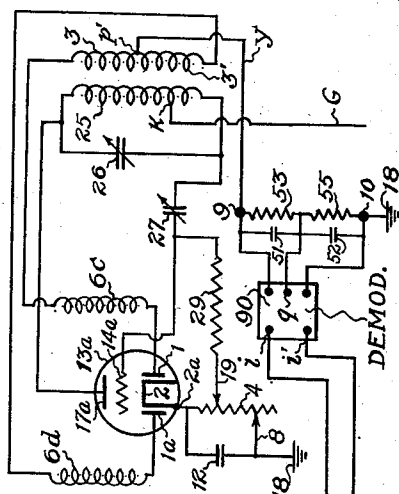
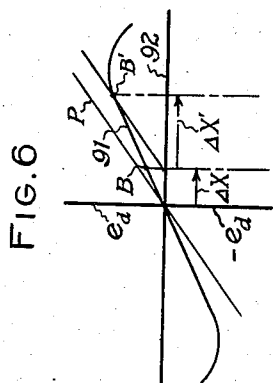
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E. H. LANGE

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DIODE MODULATOR

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INVENTOR.

Edward H. Lange.

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DIODE MODULATOR

Edward H. Lange, Baltimore, Md.

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This invention pertains to thermionic diode-modulator devices for accomplishing modulation of alternating currents in a variety of essential control-networks for reception and transmission of radio communication, by employment of impulse-excitation with predominant energy storage or reactance facilities of such modulator circuits, together with modifications of negative bias-voltage upon one or more diode-anodes, and by employment of coupling between such diode-modulator circuits and control-networks, including thermionic amplifier coupling. Among the important uses of the diode-modulator devices of this invention are amplitude-modulation in thermionic alternating current generators; limitation of alternating current amplitudes in such generators to a range providing simple harmonic oscillations, and for improvement of frequency stability together with single-frequency phase-balancing of generator circuits; frequency-modulation in thermionic wave generators; limitation of amplitudes of alternating voltages to a constant magnitude independent of amplitudes of impressed voltages beyond a selective threshold magnitude, in receivers for frequency-modulated carrier waves; phase-regeneration in frequency-demodulators for receivers of frequency-modulated carrier waves, for increasing the conversion sensitivity of such demodulators; automatic correction of tuning in superheterodyne receivers for frequency-modulated or amplitude-modulated carrier waves; and for a wave-synthesizer, for evolving output-voltage waves of varying degrees of complexity from a simple harmonic input-voltage wave, with a high degree of selective control of the output-voltage amplitudes as to their functional relationship to the input-voltage amplitudes, and of phase and frequency. These structures are hereinafter pointed out in further detail, together with important features of this invention.

The principal object of this invention, is to provide a simple diode-modulation system having a high degree of utility in radio communication receiving and transmitting circuits, to effect economies in necessary electronic equipment heretofore required to provide some of the above-stated useful operations, and to provide a new and useful system of phase-regeneration, and of amplitude, frequency, and phase control in communication networks.

An object of this invention is to provide thermionic diode-modulator devices, employing impulse excitation, together with predominant energy storage or reactance facilities of the modulator

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circuit, and with modifications of negative bias-voltage upon one or more diode-anodes, and coupling between the modulator circuit and controlled network, including the use of thermionic amplifier coupling, for controlling alternating currents of the controlled network, with a minimum of electronic equipment, and without the necessity of special thermionic tubes, or of utilizing grid control elements to the exclusion of other simultaneous uses.

Another object of this invention, is to provide such modulator devices for effecting amplitude-modulation of alternating currents in a thermionic alternating current generator; also to furnish a simple and selective control of the equilibrium currents of such alternating current generators, to confine such alternating currents to amplitudes yielding a simple harmonic waveform, and to combine with these simple harmonic currents phase-balancing of generator networks, to attain stabilization of the generated frequency.

Still another object is to furnish simple means for accomplishing frequency-modulation of the alternating currents of a thermionic alternating current generator, and to provide a new and useful system of phase-regeneration in frequency-demodulator networks, for largely augmenting the conversion sensitivity of frequency-deviations into output-voltages; also to utilize the diode-modulators of this invention to provide important tuning controls in superheterodyne receivers.

A further object, is to utilize the demodulator devices of this invention to provide a simple amplitude-limiter for use in receivers of frequency-modulated carrier currents, providing a selective control of the threshold magnitude of impressed alternating voltages, beyond which output alternating voltages are maintained constant in amplitude.

A sixth object of this invention, is to furnish a new and useful diode-modulator device for the synthesis of waves, for evolving output-voltage waves of varying degrees of complexity from a simple harmonic input-voltage wave, with selective control of incremental and decremental output-voltage amplitudes in relation to incremental input-voltage amplitudes, and of phase and frequency; also for providing inter-control of amplitudes, phase, and frequency in communication networks.

These objects, and others, will be better understood by reference to the accompanying drawings, and to the following specification and appended claims.

In the drawings,

Fig. 1 illustrates a thermionic alternating current generator, with a diode-modulator of this invention, for introducing sinusoidal degenerative voltages which are threshold determined by negative bias-voltage upon a diode-anode; also inductive coupling of the diode-modulator circuit with the generator network, for providing impulse excitation of the demodulator circuit, and means for modulating the negative bias-voltage.

Fig. 2 shows a thermionic alternating current generator, with a double-diode modulator device of this invention, employing impulse excitation with substantially pure inductive reactance in the modulator circuit, and coupled with the generator network, and with a modulation-impedance for modulating the negative bias-voltage of the diode-anodes.

Fig. 3 illustrates an amplitude-limiter device with a frequency-demodulator for converting frequency-deviations from a centre frequency of received carrier waves into corresponding output voltages upon a modulation-impedance, and modulator-devices of this invention for effecting amplitude-limitation and phase-regeneration in the demodulator network, for augmenting the conversion sensitivity of the demodulator.

Fig. 4 illustrates in graph form certain quantitative relationships showing equilibrium of alternating currents of the generator networks, and determination of amplitudes of these alternating currents in relation to the dynamic characteristic of the generator, the oscillation sustaining feedback voltage characteristic, and the negative bias-voltage determined characteristic of sinusoidal degenerative feedback voltage; also a modulating voltage modulating the negative bias-voltage, and corresponding modulation of amplitudes of the alternating currents of the generator.

Fig. 5, illustrates a sinusoidal voltage impressed upon the modulator circuit by coupling with a network to be controlled by the diode-modulator of this invention, and also illustrates the modifications effected in the time of duration and the net voltage of the impulse, available for energizing the energy-storage facilities of the modulator circuit, and in relation to modifications of the negative bias-voltage upon a diode-anode.

Fig. 6 shows a graph of a conventional demodulator characteristic for converting frequency-deviations into output-voltages, and illustrates the process of phase-regeneration for increasing the resultant output-voltage of the frequency-demodulator in relation to the amount of frequency-deviation of impressed carrier waves.

An important feature of this invention, is the employment of impulse excitation in thermionic diode circuits having predominant energy storage or reactance characteristics, and the determination of the energization of these circuits from communication networks to be controlled, by controlling threshold magnitudes of negative bias-voltage upon one or more diode-anodes, determining available voltage excess of energizing pulse above threshold magnitude, and time of duration of pulse, and in relation to natural period of oscillation of the energy storage circuit; also the modification of currents in the communication network to be controlled, by employment of threshold-determined sinusoidal voltage waves derived from oscillations in said energy storage facilities, for superposition upon grid control means of a thermionic amplifying means coupled with the communication network; and alternatively, by direct reaction in the communication

network for modifying reactance of the network directly, without intervention of the thermionic amplifying means, when the energy storage facilities of the diode circuits or impulse-excited at frequencies far removed from a natural frequency of said storage facilities.

These features, and others, are hereinafter pointed out in further detail, and in connection with the structures of this invention illustrated in the drawings.

Referring to the drawings, at 13 is a thermionic tube, having the cathode 2, anode 17, suppressor-grid 16, screen grid 15, and control-grid 14. At 1, in thermionic tube 13, is a diode-anode, forming a diode with cathode 2. At 30 is a source of unidirectional voltage for energizing anode 17, and having its negative terminal connected to ground 18; the source 30 serves also to supply a positive potential to screen-grid 15. Suppressor-grid 16 is connected directly to the cathode 2, at the cathode terminal 2a. By-pass condenser 23 connected across source 30, serves to carry alternating currents from anode 17 around the source 30; also by-pass condenser 31 connected between screen-grid 15 and ground 18, serves to by-pass alternating currents from screen-grid 15 around source 30, the impedance of condensers 28 and 31 being negligible in relation to other impedances of the circuits. The cathode terminal 2a is connected to ground 18, through resistance 4; for example by the variable contactor 8, and bias-voltage is established upon resistance 4 in a manner well understood, by passage of the steady component of current from anode 17 to cathode 2 through resistance 4, points upon resistance 4 having a negative bias-voltage relative to the terminal 2a of the cathode. At 25 is an inductance coil, tuned by the variable condenser 26 which is shunted across the coil 25. At 12 is a by-pass condenser connected from terminal 2a to variable contactor 8, for passing alternating currents around resistance 4.

Referring to Fig. 1, a thermionic alternating current generator is shown, one terminal of the coil 25 being connected directly to the anode 17, the other terminal of coil 25 being connected through the phase-balancing condenser 27 and phase-balancing resistance 29 to variable contactor 19, upon resistance 4. An intermediate junction *k* upon coil 25, is connected through conductor *G* to the positive terminal of source 30. Inductively coupled with coil 25, is the inductance coil 3, one terminal of which is connected through the terminals 9 and 10, to ground 18, the terminal 10 being connected directly to ground 18. At 11 is a modulation voltage generator connected between the terminals 9 and 10; when the modulation generator 11 is not used, or when modulation voltages are not impressed between terminals 9 and 10, the latter terminals are understood to be conductively connected together by a negligible impedance. The other terminal of coil 3 is connected to diode-anode 1, through the conductive circuit between terminals *a* and *b*. Connected between the terminals *a* and *b*, is a highly reactive circuit, capable of absorbing the major portion of the energy transferred impulsively to the diode circuit 2a-12-18-10-9-3-b-a-1-2a; such a circuit is illustrated for example by condenser 5 connected between terminals *a* and *b*, with inductance coil 6 connected between terminals *a* and *b*, condenser 5 being variable, and the circuit 5-6 having a high reactance-resistance ratio. Coupled with the coil 6 inductively, is the in-

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ductance coil 7, connected between the terminals c and d. Control-grid 14 is connected to terminal c of coil 7, and terminal d of coil 7 is connected to variable contactor 32 upon resistance 29. At 20 is a by-pass condenser of negligible impedance, connected between the variable contactor 19 and the cathode terminal 2a.

In order to better understand the operation of certain aspects of the structure of Fig. 1 of this invention, reference may next be made to Fig. 5, and to Fig. 4. In Fig. 1, when the coil 3 is uncoupled from coil 25, and terminals c and d short-circuited by a conductor of negligible impedance, a conventional form of thermionic alternating current generator exists, with phase-balancing means, and means for adjusting both the negative bias-voltage and the oscillation-sustaining alternating fed-back voltage upon the control-grid 14. Means have heretofore been provided for phase-balancing thermionic alternating current generators to reduce the well known inconstancy of generated frequency of such generators; such phase-balancing is premised upon a single simple harmonic frequency, which condition does not exist when the oscillatory currents are allowed to reach their equilibrium magnitude in the conventional manner. Thus, for example in the generator of Fig. 1, a small reactance may be introduced by the variable condenser 27, together with the high resistance 29, to shift the phase of the oscillation-sustaining or regenerative voltage upon the control-grid 14, between 14 and cathode terminal 2a, and by a small phase-angle sufficient to maintain the regenerative voltage in exact phase-opposition to the vector sum of the voltage across the external impedance, e. g. between cathode 2 and anode 17, and the voltage drop internally, through the impedance of the thermionic tube between cathode 2 and anode 17, and at the natural, undamped frequency of oscillation of the resonant system. Such a phase-balance provides improvement of frequency-stability in reference to random changes in thermionic tube resistance between cathode 2 and anode 17, and so far as the fundamental natural frequency alone is concerned; other means for accomplishing such phase-balancing with reference to a simple harmonic natural frequency are known, for example Method and means for normalizing thermionic oscillators, U. S. Patent No. 2,305,362 of the present inventor, and wherein the above-indicated phase-balance is effected to avoid the necessity of the oscillator to shift frequency to establish a new equilibrium, when the tube resistance or oscillatory circuit resistances are modified. Such phase-balancing is limited in effectiveness by the fact that a simple harmonic generated frequency does not exist, when the generator alternating current is allowed to reach its equilibrium magnitude in the conventional manner; harmonics are present in varying degrees, which limit the effectiveness of the above-described phase-balance for stabilizing the generated frequency. The present invention provides simple means for limiting the generated frequency to a single frequency by threshold-limiting of alternating grid-cathode voltages to any desired medium, as well as for modulating the amplitudes of the single generated frequency.

Referring to Fig. 5, at 60 is shown a sinusoidal voltage wave of amplitude E, and with reference to the time axis indicated by 63. At 62 is indicated a line defining a negative bias-voltage upon the diode-anode 1, relative to cathode 2, and set for example by the variable contactor 8. The

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voltage 60 represents a voltage set up in coil 3 by inductive coupling with the coil 25, and the shaded portion 61 indicates instantaneous values of excess of positive voltage $E - e_{do}$, above a negative bias-voltage of magnitude e_{do} . The time of a half-cycle of the voltage of maximum value E, is indicated by $\tau/2$, and the time of duration of the positive voltage impulse upon the diode-anode 1 as modified by the negative bias-voltage is indicated by τ' . When the condenser 5 with inductance coil 6 is tuned to the fundamental generated frequency of the currents in the oscillatory circuit 25—26 of the thermionic alternating current generator, the tuned circuit 5—6 receives an energizing pulse once every cycle. The circuit 5—6, Fig. 1, has a high reactance-resistance ratio; the effective resistance between the terminals a and b is high in relation to the resistance of the diode 1—2, and the major portion of voltage drop of the diode circuit is upon the circuit a—b. Also, the decrement of the oscillatory circuit 5—6 is then very small, and substantially constant amplitude is maintained for the alternating voltage between terminals a and b, and during the time between energy impulses. The alternating voltage upon the coil 6 is thus modified in relation to amounts of negative bias voltage e_{do} , and correspondingly modified threshold-determined sinusoidal voltages are set up in the coil 7, no sinusoidal voltage being developed in the coil 7 until the voltage E exceeds the adjustable negative bias-voltage e_{do} . Alternating voltages are thus developed across the terminals a—b, and in proper phase relationship, by means of a highly reactive network, to provide degenerative voltages with respect to the regenerative or oscillation-sustaining voltages upon the resistance 29, these degenerative voltages being threshold-determined. An important feature of this invention is the provision of means for producing threshold controlled sinusoidal voltages, as distinguished from threshold controlled voltages having harmonics, as for example when the highly reactive circuit between terminals a and b is replaced by a high resistance; in this latter case only bias-excess portions of sine waves are transmitted upon the high resistance between terminals a and b, for degenerative purposes, or for voltage limiting purposes.

Referring to Fig. 4, at 67 is indicated a dynamic characteristic of a thermionic alternating current amplifier, showing a typical relationship between the effective values of alternating voltage impressed upon a control-grid, e. g. grid 14, and alternating currents between cathode and anode, with an external impedance, e. g. as in Fig. 1, when separately excited. At 75 is indicated an oscillation-sustaining feed-back voltage characteristic, showing the feed-back voltage available for any particular cathode-anode alternating current, in relation to the alternating voltage required for said current, as indicated by the characteristic 67. At 68 is indicated an equilibrium value of alternating current of the alternating current generator, determined by equality of the required and available alternating voltages, in conventional forms of thermionic alternating current generators. The characteristic 67, has a straight-line relationship between impressed alternating voltage and resultant cathode-anode alternating current for a substantial portion, over which sinusoidal currents result from impressed sinusoidal voltages; beyond this portion the resultant alternating currents have harmonics, introduced for example by cut-off of cathode-anode

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current through large negative grid voltages, and other causes. An important feature of the present invention is the means for introducing degenerative sinusoidal voltages, after a selective magnitude of alternating voltage upon the control-grid is reached.

At 70 is indicated a characteristic of degenerative feed-back, showing the alternating voltage for opposing the regenerative feed-back voltages, and in relation to cathode-anode alternating currents between 2a—17. Thus at the particular alternating current indicated by the point 73, the degenerative feed-back voltage is zero; this particular threshold magnitude being determined by the fact that the specific negative bias-voltage indicated by e_{a0} is sufficient to prevent impulse excitation of the resonator circuit 5—6. As greater alternating voltages are impressed upon the coil 3, degenerative voltages appear across the terminals c—d, and in relation to increasing alternating currents between cathode 2 and anode 17, as indicated along the axis of ordinates; alternating currents between cathode 2 and anode 17 being indicated by I_p , and alternating voltages upon grid 14 being indicated by E_g , along the axis of abscissas. Thus for the specific alternating current indicated by 76, if the grid 14 were separately excited, an alternating voltage corresponding to the abscissa of the point 74 would be required upon grid 14, whereas the feed-back voltage available with this current, and for sustaining oscillations, is indicated by E'_g ; the degenerative voltage available is indicated by E''_g . The resultant regenerative voltage is thus $E'_g - E''_g$, and equilibrium alternating current of the thermionic alternating current generator is determined therefore at the magnitude indicated by the point 74 along the straight-line part of the characteristic 67, instead of at the point 68. If the negative bias-voltage is modified to an amount indicated by the line 78, for the diode-anode 1, the degenerative voltage characteristic is shifted to the line 71, and the equilibrium alternating current of the thermionic alternating current generator is shifted to the magnitude indicated by the point 77. At 79, is indicated a graph of modulating voltage upon the diode-anode 1, in relation to time, the modulating voltages being indicated at any instant by e_a , superposed upon the set negative bias-voltage e_{a0} , and such that the maximum positive value of e_a does not exceed the value of the set negative bias-voltage e_{a0} . The resultant bias-voltage upon the diode-anode 1 is thus always negative, and modified in relation to the passage of time. At 79' is indicated the corresponding graph of the envelope of the high-frequency sinusoidal current waves of the thermionic generator, showing the amplitude-modulation of these current waves in response to modified negative bias-voltages upon the diode 1.

Thus, the circuit of Fig. 1, can be employed for frequency-stabilization alone, or also for amplitude-modulation of the alternating currents; in the former instance the terminals 9—10 are joined by a conductor having but small impedance in relation to the impedance of the diode-connected circuit, and in the latter instance this conductor is omitted, the conductive circuit being completed through the source 11 for providing modulation voltages across the terminals 9—10, to modulate a resultant negative bias-voltage upon the diode-anode 1. The frequencies of the modulation voltages are understood to be less than the frequencies generated by the thermionic alternating current generator.

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With reference to the employment of Fig. 1 for frequency-stabilization, it will be noted that the generated alternating currents are limited to simple harmonic alternating currents of single selectable frequency, providing the facility for precise adjustment of phase of the regenerative feed-back voltage by condenser 27, or other means previously referred to herein; likewise the threshold-determined alternating degenerative voltages impressed upon the control-grid 14 are maintained in substantial phase-opposition to the regenerative voltages, through control of phase-angle of the diode-connected circuit, e. g. by ratio of reactance of coil 3 to reactance and resistance of the circuit between the terminals a and b. Other phase-determining networks for impulse excitation, may be employed between the terminals a—b, and c—d, in a manner well understood; for example quadrature-phase voltages may be obtained across the terminals c—d by tuning the coil 7, or by other well known circuit means.

The operation of the grid-voltage amplitude-limiting structure of Fig. 3 is similar to that described for Fig. 1, in reference to Figs. 4 and 5; in this instance the degenerative alternating voltage between the terminals c and d increases at nearly the same rate with increase of cathode-anode alternating current between 17 and 2, above the threshold magnitude of alternating input voltage upon control-grid 14, as the impressed alternating input voltage increases in relation to this alternating current which it produces. Thus the effect of any increase in alternating input voltage upon the grid 14 is annulled, the threshold magnitude beyond which increases in input alternating voltage produce no further increase in the output voltage, being selectively determined by the variable contactor 8'. Such amplitude-limitation is useful in receivers for frequency-modulated carrier-waves, and the structure of Fig. 3 provides both selector means for controlling the limited voltage, and means for providing amplitude-limited sinusoidal waves as distinguished from distorted or irregular shaped waves of constant amplitude.

Referring to Fig. 2, a thermionic alternating current generator is illustrated, with thermionic tube 13a having anode 17a connected to one terminal of coil 25, the other terminal of coil 25 being connected to the resistance 4, through the variable condenser 27 in series with resistance 29; one terminal of resistance 29 is connected to the variable contactor 19 upon resistance 4, and the other terminal of resistance 29 is connected to the control-grid 14a of tube 13a. With cathode 2, are the respective diode-anodes 1 and 1a, each providing with cathode 2 a separate diode. Resistance 4 is connected from cathode terminal 2a to the ground 18, through variable contactor 8 upon resistance 4. Coils 3 and 3' are inductively coupled with the coil 25; these coils have equal self-inductance, and are connected in series at the junction p'. It will be understood that a single coil may be used for coils 3 and 3', with the junction p' at the half-inductance point upon the single coil. Connected between the diode-anode 1 and the terminal of coil 3 opposite junction p', is the reactance coil 6c, and connected between the diode-anode 1a and the terminal of coil 3' opposite junction p', is the reactance coil 6d. The reactance coils 6c and 6d have a high reactance in relation to resistance of the coils, and coils 6c and 6d have equal self-inductance. The combined series reactance of coils 6c and 3 is large in relation to the resistance of the diode

1—2, and likewise the combined series reactance of coils 6*a* and 3' is large in relation to the resistance of diode 1*a*—2, the circuits containing substantially pure inductive reactance. Connected between the junction *p*' and the terminal 9, is the conductor *y*. The terminal 9 is connected to ground 18, through the modulation-impedance connected between the terminals 9 and 10, having the conductive path through the equal resistances 55 and 53, in series, terminal 10 being connected to ground 18. At 90 is illustrated in block-diagram form a conventional demodulator, connected to the modulation-impedance between terminals 9 and 10; it is understood for the purposes of this invention that modulation voltages are provided between the terminals 9 and 10. Thus for example with a conventional frequency-demodulator having frequency-modulated carrier waves impressed upon the input-terminals *i* and *i*', amplitude-modulated voltages are made available upon a modulation-impedance connected between the terminals 9 and 10, proportional to the amounts of frequency-deviation of the carrier waves, in a manner well understood. Such a conventional form of frequency-demodulator is further illustrated in Fig. 3, in detail. The impedance between terminals 9 and 10 for frequencies of the thermionic generator, is understood to be negligible in relation to the reactance of the diode circuits, between diode-anode 1 and junction *p*', and between diode-anode 1*a* and junction *p*', because of by-pass condensers 51 and 52, respectively across the resistances 53 and 55, and the frequencies of the modulation voltages across 9 and 10 to be low in relation to the frequencies of the thermionic alternating current generator.

Operation of the diode-modulator of the structure, Fig. 2, for utilizing threshold-controlled impulse-excitation of the highly reactive diode circuits to modulate the generated frequency of the thermionic alternating current generator, may be understood from the following considerations. Without any modulating voltage present between terminals 9 and 10, the negative bias-voltage upon diode-anodes 1 and 1*a* is controlled by the contactor 8 upon resistance 4; if this bias-voltage is set to zero, by contactor 8, then a full half-cycle voltage impulse in coil 3 from coil 25, is operative, and likewise a full half-cycle impulse in coil 3' from coil 25, is operative a half-period later, to supply a current pulse through the highly reactive diode circuit. When negative bias-voltage is introduced by way of contactor 8, the duration of the voltage pulse effective for determining a current pulse, is reduced, and likewise the effective magnitude of the voltage pulse is reduced, resulting in reduced alternating currents in the coils 3—3' with the same induced voltage in 3—3' from coil 25, and in an increase of the effective reactance of the diode circuits.

In the structures heretofore disclosed herein, direct reaction of the diode circuit in the network to be controlled has been negligible, only sufficient coupling being necessary to set up control voltages for controlling a grid of a thermionic tube coupled with the network to be controlled; in the present structure however, no grid connection is employed with the diode-modulator, directly. The diode circuits 2—12—18—52—51—*p*'—2—6*c*—1—2, and 2—12—18—52—51—*p*'—3'—6*d*—1*a*—2, are substantially purely reactive circuits, and are sufficiently tightly coupled inductively with the coil 25 to modify the resultant reactance of coil 25 at the frequencies of the alternating current thermionic generator. From well

known relations for such coupled circuits, if the inductance of coil 25 alone is designated by L_{25} , the mutual inductance between coil 25 and the diode circuit coils 3, 3', by M , and the total self-inductance of either diode circuit by L_0 , the resultant self-inductance of the coil 25 coupled with the diode inductance is:

$$L'_{25} = L_{25} - M^2/L_0 \quad (1)$$

when modification of the currents through inductance L_0 is not effected by a negatively biased thermionic diode. When modification of the inductance L_0 is effected by controlling the resultant negative bias-voltage upon the diode-anodes, it can readily be shown that instead of L_0 , the resultant self-inductance of the diode-circuits is of the form:

$$L'_0 = \frac{L_0}{1 - \frac{\pi}{2}\alpha + \frac{\alpha^2}{2}} \quad (2)$$

As employed in Fig. 2 for frequency-modulation, an initial negative bias-voltage e_{d0} , is set upon the resistance 4 by the contactor 8. In Equation 2 the parameter α is defined by the ratio of the resultant negative bias-voltage upon the diode-anodes to the voltage E_3 set up in either coil 3 or coil 3', from coil 25. When both positive and negative modulating voltages are employed upon the modulation-impedance, as for example when the modulation-impedance is connected to the output side of a frequency-demodulator, the negative bias-voltage set at the contactor 8 is such as to be always greater than the maximum positive voltage upon the modulation-impedance, between terminals 9 and 10, so that the resultant bias-voltage upon the diode-anodes 1 and 1*a* is always negative.

Referring to Fig. 3, the diode-modulator devices of this invention are shown in connection with a frequency-demodulator, for providing amplitude-limitation of input-voltages upon the demodulator and for providing phase-regeneration in the demodulator circuit, to largely increase the ratio of output-voltage of the demodulator in relation to the amount of frequency-deviation of the frequency-modulated input-voltages. Connected with the anode 17 of tube 13, is a conventional form of frequency-demodulator circuit, one terminal of coil 25 being connected to anode 17, and the other terminal of coil 25 being connected to the positive terminal of source 30. Condenser 26 is shunted across coil 25. At 56 is a secondary coil, coupled with coil 25 inductively. Shunted across coil 56 is the condenser 41. At 42 is a thermionic tube, having diode-cathode 45 with diode-anode 44, and diode-cathode 46 with diode-anode 47. Connected between terminals 9 and 10, is the resistance 53 in series with the resistance 55, these resistances being equal. Shunted across resistance 53 is condenser 51, and shunted across resistance 55 is condenser 52. Terminal 9 is connected to diode-cathode 45, and terminal 10 is connected to diode-cathode 46. Choke-coil 40 is connected between the half-inductance junction *j* upon coil 56 and the junction *q* between resistances 53 and 55. Connected between the anode 17 and the junction *j*, is the low-impedance condenser 43. The circuit described, and connected with the anode 17, comprises a conventional type of frequency-demodulator. The improvements effected by the diode-modulators of this invention, will be evident from the following details. At *i* and *i*' are input terminals, inductively coupled with the coil 25*a*, and condenser

26a is shunted across the coil 25a. Cathode 2 of tube 13, has the diode-anode 1, and the diode-anode 1a. Resistance 4 is connected between cathode terminal 2a and ground 18, through variable contactor 8. Connected between diode-anode 1a and variable contactor 8' upon resistance 4, is the coil 3' in series with the terminals a—b; coil 6 is connected between terminals a and b, condenser 5 is shunted across coil 6, and coil 3' is inductively coupled with coil 25. By-pass condenser 20 is connected between contactor 8' and cathode-terminal 2a. One terminal of coil 25a is connected to control-grid 14, and the other terminal of coil 25a is connected to variable contactor 19 upon resistance 4, through the terminals c—d, the coil 7 being connected between the terminals c and d, and coupled with the coil 6. By-pass condenser 12b is connected between the contactor 19 and cathode-terminal 2a, and by-pass condenser 12a is connected between contactors 19 and 8. Suppressor-grid 16 is connected to cathode-terminal 2a, and screen-grid 15 is connected through conductor 30a to a positive potential upon source 30. The above-described modulator device with cathode 2 and diode-anode 1a, provides a voltage limiting device, selectively limiting the amplitudes impressed upon the frequency-demodulator.

Diode-modulator device including diode-anode 1 with cathode 2, provides phase-regeneration in the demodulator circuit, whereby voltages established across the modulation-impedance between the terminals 9—10, of the frequency-demodulator, and responsive to the amount of frequency-deviation of the carrier waves from a centre-frequency, through changes in phase of voltages upon the demodulator circuit, are employed to further modify such changes in phase to increase the conversion sensitivity of the demodulator for converting frequency-deviations to output voltage between terminals 9—10. Diode-anode 1 is connected through the high reactance coil 6c and coil 3 in series, through conductor 48 to the terminal 9 upon the modulation-impedance, the coil 3 being inductively coupled with the demodulator network. Variable contactor 19 serves to adjust the negative bias-voltage upon grid 14, variable contactor 8' serves to adjust the negative bias-voltage upon diode-anode 1a for impulse-excitation of the circuit between terminals a—b, and variable contactor 8 serves to adjust the negative bias-voltage on the diode-anode 1, through the circuit 2—4—8—18—10—9—48—3—6c—1—2, for impulse-excitation of the reactance coils 6c and 3. The operation of the diode-modulator in modifying a resultant inductive reactance of a coupled network, has been described with reference to Fig. 2. Without phase-regeneration, an incremental change in resultant reactance is effected in the demodulator network by a change in frequency, that is, by a frequency-deviation from the centre carrier frequency; thus if this incremental reactance change is indicated by ΔX , then:

$$\Delta X = 4\pi L \Delta f \quad (3)$$

in which Δf is the incremental frequency change, or frequency-deviation, and L the inductance determining differential output-voltage upon the modulation-impedance between terminals 9—10. Referring to Fig. 6, at 91 is shown a typical graph relating frequency-deviation to output-voltage upon the modulation-impedance, for conventional forms of frequency-demodulators, the output-voltage indicated by e_a being of opposite

polarity for positive frequency-deviations in relation to the polarity for negative frequency-deviations. At $\Delta X'$, is indicated an additional change of reactance of the inductance L, established by the diode-modulator including the diode-anode 1. The regenerative phase-amplification thus established will be apparent from Fig. 6. Due to modification of the inductance L, by the amount ΔL , through action of the modulator-device, there is a further change of reactance of

$$\Delta X' = 2\pi f_c \Delta L \quad (4)$$

wherein f_c is the centre-frequency of the carrier waves, and ΔL change of inductance effected, in the equilibrium condition. At P is indicated the phase-reflex line, relating reactance change available through phase-regeneration, for any particular modulation-voltage e_a , between the terminals 9—10; at 91 is indicated the line relating reactance change required to produce the particular voltage e_a , by frequency-modulation alone, the frequency-deviations being measured along the axis of abscissas, 92. Thus at the equilibrium point indicated by B', the total reactance change is indicated by $\Delta X + \Delta X'$, of which only the amount ΔX is established by frequency-deviations, directly, and the resultant output-voltage between the terminals 9—10 is indicated by the ordinate at B', instead of by the normal output-voltage indicated by the ordinate at B. The resultant phase-regenerative amplification of the output-voltages is thus seen to be defined by the ratio:

$$A = \frac{1}{1 - D/D'} \quad (5)$$

in which D is the slope of the demodulator characteristic, and D' the slope of the phase-reflex line P, and D' is greater than D.

It will be understood, that the polarity of modulating voltage applied to the diode-modulator from terminals 9—10, in relation to frequency-deviation, is such as to augment the conversion sensitivity, the polarity being selective; also that the scope of this invention is not limited to employment of phase-regeneration in the specific frequency-demodulator here illustrated, there being other forms of frequency-demodulators employing phase-shift to determine output-voltages, for example, Thermionic device for converting frequency-modulation into amplitude-modulation, U. S. Patent No. 2,369,055, February 6, 1945, of the present inventor. It will likewise be evident that when the opposite polarity is selected, the modification of tuning of the demodulator network is in the opposite sense, toward a tuned condition instead of toward increase of de-tuning.

Referring to the principal object of this invention, it will be understood that a super-heterodyne receiver may employ the diode-modulator devices of this invention for automatic adjustment of tuning of the demodulator to intermediate-frequency, or for phase-regeneration in the demodulator, and that the demodulator may include a diode-modulator device for limiting the amplitudes, when receiving frequency-modulated carrier waves. The mixer or frequency-reducer of the super-heterodyne is understood to have a thermionic alternating current generator, for example as described herein, and containing a diode-modulator as described, for modifying the frequency of the generator, without the necessity of a separate reactance-modulator tube.

Operation of the diode modulated device of this

invention as a wave-synthesizer will first be described with reference to the simplest employment of the device, for controlling the functional relationship between the amplitudes of impressed sinusoidal waves e. g. upon coil 25, Fig. 3, and the amplitudes of sinusoidal output-voltages e. g. at the terminals *c—d*, Fig. 3. It will be understood that more than one diode modulator may be energized from coil 25, and independently biased by means of a variable contactor such as 8' upon resistance 4. In this usage, threshold voltages either in phase-conjunction, or phase-opposition, or combinations of these, are employed in the circuit connecting the output terminals such as *c—d*. Thus, as the amplitudes of the impressed voltage across coil 25 are increased, the amplitudes of the output-voltages may be controlled to conform to various functional relationships; a few examples will illustrate the synthesis of relative wave amplitudes.

It will be evident that the negative bias-voltages can be spaced so that the various impulse-excited circuits contribute to the total output-voltage in a sequence, as the impressed voltage increases sufficiently to exceed the threshold values. Thus, increments to the output-voltage can be supplied in a sequence, so that the output-voltage in the circuit connecting the output-terminals such as *c—d* increases in relation to the input-voltage in a relation approximating the *N*-th power of the input-voltage, *N* being greater than unity. Or, alternatively, all degenerative or phase-opposing voltages can be introduced in sequence into the circuit connecting said terminals, to approximate the *N*-th power relation, *N* being fractional. Or alternatively, combinations of threshold controlled phase-aiding and phase-opposing voltages can be used, providing output-voltage characteristics which are concave downward for a range, and then concave upward, or alternatively, concave upward for a range and then concave downward. Other functional relations will be apparent, and in relation to the multiplicity of diode-modulator circuits employed.

An important feature of the functional relations so evolved, is the facility for providing non-linear relationships between impressed and output-voltages, without the necessity of distortion of the output wave-shape, as in the case of conventional forms of transmission through non-linear conductors; in the above process sinusoidal threshold-controlled incremental or decremental voltages are employed, providing a sinusoidal resultant.

Many threshold-determined phase-shift relationships may be evolved; a single illustration will suffice. When one of the impulse-excited transfer circuits provides the facility for introducing quadrature-voltage components, as heretofore described, threshold-determined phase-shifts are obtainable. For example, with a single diode-anode device, e. g. with diode-anode 1a, a sinusoidal resultant voltage can be made to increase linearly with the input-voltage until a set magnitude is reached, after which the resultant voltage begins to shift phase relative to the input-voltage.

In the employments of impulse-excitation described, the tuned transfer circuits have been tuned to the frequency of excitation impressed upon the modulator circuits, that is, when the source of excitation has a frequency *F*, the tuned transfer circuits are also tuned to the frequency *F*. With this usage, one energy impulse is impressed upon the transfer circuit for each cycle of impressed voltage, and per diode-anode con-

nected with the oscillatory transfer circuit. Excitation of a transfer circuit having tunable oscillatory facilities as illustrated, may however, be effected for maintaining alternating currents in the transfer circuit by furnishing energy impulses less frequently than one per cycle of natural oscillations of the transfer circuit. Thus, if the transfer circuit is tuned for twice the frequency of the impressed voltage upon the diode-modulator, energy impulses can be furnished to the transfer circuit of duration equal to, or less than, the time of one half-cycle of the double frequency, as illustrated in Fig. 5 showing duration τ' and magnitude of positive pulse upon a diode-anode, in relation to negative bias-voltage upon the diode-anode, and to the voltage impressed upon the diode circuit. Similarly, when the oscillatory transfer circuits are tuned for multiple frequencies of the frequency impressed upon the diode-modulator circuit, multiple frequency alternating currents can be maintained in the transfer circuits, through negative bias-voltage control of the time τ' of impulse excitation. When an alternating voltage of frequency *F* is impressed upon the circuit 25—26, output-voltages can thus be made available at the output terminals such as *c—d*, with harmonic frequencies selectively controlled as to amplitude and phase.

In the diode-modulators herein described, coupling for supplying impulse-excitation has been illustrated between the diode-circuit and the output-impedance of a thermionic amplifier; it will be evident that this coupling can alternately be with the input-impedance, and likewise the impulse-excited resonator coupled with the input-impedance for combining alternating voltages from the input-impedance with threshold-controlled alternating voltages from the resonator reactance network, e. g. for application of the combined voltages between the grid and-cathode of a thermionic tube, for effecting controls heretofore described, herein. Coupling with the output-impedance affords larger available voltages for impulse-excitation, and correspondingly larger threshold-controlled alternating voltages.

Having described several illustrative embodiments of my invention, it will be evident that changes can be made in the form and arrangement of parts, and by substitution in part of other well known structures, or otherwise, without departing from the spirit of my invention, and I do not therefore limit the scope of the invention to such particular embodiments.

What is claimed is:

1. In a thermionic amplifier having a thermionic tube with cathode, anode, and grid, an input-impedance connected to said grid and to said cathode, and an output-impedance connected to said cathode and to said anode, a diode-modulator device for controlling phase and magnitude of alternating currents in said output-impedance, said device having a thermionic diode means including a diode-anode with said cathode, a diode-circuit connected between said diode-anode and cathode, including connections serially through a negative bias-voltage control means for controlling negative biasing of said diode-anode relative to said cathode, and through a tuned reactance-circuit capable of free electrical oscillations with small decrement at a frequency of said alternating currents; a first coupling means coupling said diode-circuit with said output-impedance, and a second coupling means coupling said tuned reactance-circuit with said input-impedance, for

controlling phase and magnitude of voltages upon said input-impedance.

2. In combination with the structure of claim 1, a third coupling means coupling said output-impedance with said input-impedance for generating said alternating currents, a modulation-impedance in series with said diode-circuit, and modulating-voltage means connected with said modulation-impedance, for varying the resultant negative bias-voltage upon said diode-anode, to modulate said alternating currents.

3. A diode-modulator device for modulating alternating current amplitudes, in an alternating current thermionic generator having a thermionic tube with cathode, anode and grid, an input-impedance connected between said cathode and grid, an output-impedance connected between said cathode and anode, and a coupling means coupling said input-impedance with said output-impedance, said device having a thermionic diode means including a diode-anode with said cathode, a circuit connected between said diode-anode and cathode including connections through a negative bias-voltage means for negatively biasing said diode-anode relative to said cathode, an inductance coil shunted by a condenser, tuned to said alternating currents, and a modulation-impedance; a first coupling means coupling said circuit with said output-impedance, a second coupling means coupling said inductance coil with said input-impedance, impressing degenerative alternating voltages upon said input-impedance, and modulating-voltage means connected to said modulation-impedance, for varying the resultant negative bias-voltage upon said diode-anode.

4. A diode-modulator device for modulating alternating currents in a thermionic alternating current generator having a thermionic tube with cathode, anode, and grid, an input-impedance connected between said grid and cathode, an output-impedance connected between said cathode and anode, and a coupling means coupling said input-impedance with said output-impedance, said device having a thermionic diode means including a diode-anode with said cathode, a diode-circuit connected between said diode-anode and cathode serially including connections through a negative bias-voltage means for negatively biasing said diode-anode, a transfer-impedance including a resonator-circuit for controlling phase of transferred voltages, and a modulation-impedance; a first coupling means coupling said diode-circuit with said output-impedance, a second coupling means coupling said transfer-impedance with said input-impedance, in quadrature with the voltages upon said output-impedance, and modulating-voltage means connected to said modulation-impedance, for varying the resultant negative bias-voltage upon said diode-anode.

5. The combination with a thermionic amplifier having a thermionic tube with a cathode, grid, and anode, an output-impedance connected between said anode and cathode, and an input-impedance connected between said grid and cathode, of a diode-modulator device for limiting alternating voltages upon said output-impedance to a substantially constant magnitude, independent of increases of alternating voltages upon said input-impedance beyond a selectable norm; said device having a thermionic diode means including a diode-anode with said cathode, a circuit connected between said diode-anode and cathode including connections with a bias-voltage control means for controlling negative biasing of said diode-anode relative to said cathode, a resonator-

circuit means including an inductance coil shunted by a condenser, tuned by said condenser to said alternating voltages and capable of free electrical oscillations of small decrement, and a coupling impedance; a first coupling means coupling said coupling-impedance with one of said amplifier impedances, and a second coupling means coupling said resonator-circuit means with said input-impedance, impressing voltages upon said grid of opposite phase to said input voltages, when said input voltages exceed said norm, selectably determined by the magnitude of said negative bias-voltage upon said diode-anode.

6. The combination with a frequency-demodulator for converting frequency-modulated carrier currents to amplitude-modulated output-voltages, of a diode-modulator device, for increasing the conversion sensitivity of said demodulator, said demodulator having a phase-shifting network determining said amplitude-modulated output-voltages responsive to variations of frequency of the carrier currents, and an output-impedance for said amplitude-modulated output-voltages, said device having a diode with diode-anode and diode-cathode, a circuit between said diode-anode and diode-cathode including connections with a negative bias-voltage control means for controlling negative biasing of said diode-anode relative to said diode-cathode, and an inductive impedance; a first coupling means coupling said inductive impedance with said phase-shifting network, and a second coupling means coupling said negative bias-voltage control means with said output-impedance, for increasing the resultant phase-shift in said phase-shifting network initiated by a variation of frequency of said carrier currents.

7. A diode reactance-modulator device for modifying reactive alternating voltages in a phase-shifting network, said device having a thermionic tube with a cathode and a diode-anode with said cathode, control-circuit means connected between said cathode and diode-anode comprising a negative bias-voltage control means including a modulation-impedance means for controlling negative biasing of said diode-anode relative to said cathode, and an inductance coil means having large reactance relative to the resistance between said cathode and diode-anode, to the inherent resistance of said coil means, and to said modulation-impedance means, said means being serially connected; inductive coupling means coupling said control-circuit means with said phase-shifting network for transfer of energy, and voltage-control means connected with said modulation-impedance means for controlling the resultant negative bias-voltage upon said diode-anode, to control the stored energy of said control-circuit means.

8. In combination with the structure of claim 7, said thermionic tube having a second anode and a grid for controlling thermionic currents between said cathode and said second anode, said phase-shifting network being connected between said cathode and said second anode, an input-impedance connected between said grid and said cathode, and a second coupling means coupling said control-circuit means with said input-impedance.

9. In a thermionic amplifier having a thermionic tube with a cathode, a grid, and an anode, an input-impedance connected to said grid and to said cathode, and a phase-shifting network connected to said anode and to said cathode, including connections with an energizing source for

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said anode-cathode, a diode-modulator device for modifying the alternating currents in said network, said device having a diode means including a diode-anode with said cathode, conductive diode-circuit means including said diode-anode and cathode comprising predominant energy-storage means, said circuit means including connections with a negative bias-voltage means for negatively biasing said diode-anode relative to said cathode, and a diode-inductance means for storing substantially all of any energy-impulse transmitted through said diode means from said network through excess of positive voltage upon said diode-anode over said negative bias-voltage; coupling means coupling said diode-circuit means with said network, and a regulating means regulating magnitude of said negative bias-voltage upon said diode-anode.

10. In combination with the structure of claim 9, a modulation-impedance connected in series with said diode-circuit means, and voltage-modulating means connected with said modulation-impedance for varying the resultant negative bias-voltage upon said diode-anode.

11. In combination with the structure of claim 9, a second coupling means coupling said diode-inductance means with said input-impedance.

12. In combination with the structure of claim 9, condenser means connected with said diode-inductance means for tuning said diode-circuit means, and a second coupling means coupling said diode-inductance means with said input-impedance.

13. In combination with the structure of claim 9, condenser means for tuning said diode-inductance means, a modulation-impedance connected in series with said diode-circuit means, voltage-modulating means connected with said modulation-impedance for varying the resultant negative bias-voltage upon said diode-anode, and a second coupling means coupling said diode-inductance means with said input-impedance, for regulating magnitude and phase of alternating voltages upon said grid from said diode-circuit means.

14. In combination with the structure of claim 9, a second coupling means coupling said input-impedance with said network for producing self-sustained alternating currents, condenser means for tuning said diode-inductance means, and a third coupling means coupling said diode-inductance means with said input-impedance, for regulating magnitude and phase of alternating voltages upon said grid from said diode-circuit means.

15. In combination with the structure of claim 9, a second coupling means coupling said input-impedance with said network for providing self-sustained alternating currents, condenser means for tuning said diode-inductance means, a third coupling means coupling said diode-inductance means with said input-impedance, regulating phase and magnitude of alternating voltages upon said grid from said diode-circuit means, a modulation-impedance connected in series with said diode-circuit means, and voltage-modulating means connected with said modulation-impedance for modifying the resultant negative bias-voltage upon said diode-anode.

16. The combination with a frequency-demodulator for converting frequency-modulated carrier currents into amplitude-modulated output-voltages, of a phase-modulator device for modifying the specific amount of phase-shift in said demodulator for any constant frequency-deviation of said impressed carrier currents, said de-

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modulator having a phase-shifting network and an output-impedance for amplitude-modulated output-voltages, said device having a reactance-modulator means including a bias-voltage control means, a first coupling means coupling said output-impedance with said reactance-modulator means for controlling said bias-voltage means of said reactance-modulator means, and an energizing means for impulsively energizing said reactance-modulator means from said phase-shifting network including a second coupling means coupling said reactance-modulator means with said phase-shifting network of said demodulator, modifying the specific amount of phase-shift in said network for any constant frequency-deviation of said carrier currents impressed upon said demodulator responsively with the amount of said frequency-deviation.

17. A diode-modulator device for synthesizing alternating voltages from an impressed alternating input-voltage, said device having a voltage transfer-circuit including an input-impedance for impressing said alternating voltages and an output-impedance coupled with said input impedance, a diode having a cathode and a diode-anode with said cathode, a tuned transfer-impedance capable of free electrical oscillations of small decrement, having input-terminals, output-terminals, and a conductive path between said input-terminals, a bias-voltage control means having a positive terminal connected to said cathode, a conductive circuit between said diode-anode and a negative terminal upon said bias-voltage control means, including said conductive path through said input-terminals of said transfer-impedance and a conductive path through a diode-coupling means coupling said conductive circuit with said transfer-circuit for impulsively energizing said transfer-impedance; and the circuit means for combining voltages upon said transfer-circuit including said output-terminals of said transfer-impedance.

18. A modulator device for modifying alternating voltages upon an electrical filter-circuit, said device having a diode means including a cathode and a diode-anode, a diode circuit connected between said diode-anode and cathode including a tuned-reactance resonator means capable of free electrical oscillations of small decrement, a first coupling means coupling said diode circuit with said filter-circuit for impulsively exciting resonance oscillations in said tuned-reactance resonator means, a negative bias-voltage control means connected with said diode circuit for controlling amount of negative bias-voltage upon said diode-anode, and controlling impulse-excitation of said tuned-reactance resonator means responsively with excess of positive impulse-voltage upon said diode-anode above said negative bias-voltage, and a second coupling means coupling said tuned-reactance resonator means with said filter-circuit, for combining impulse-excited oscillatory voltages from said tuned-reactance resonator means with alternating voltages upon said filter-circuit, and for controlling the phase and magnitude of said combined voltages.

19. A diode reactance-modulator device for modifying reactive voltages upon a phase-shifting network, said device having a diode rectifying means including a diode-anode with a cathode, conductive diode-circuit means including said means, comprising predominant energy-storage means conserving substantially all of any energy-impulse upon said diode-circuit means, including inductance means and a negative bias-voltage

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control means for controlling the amount of negative bias-voltage of said diode-anode relative to said cathode, said means being serially connected; energizing means for impulsively energizing said inductance means from energy of said phase-shifting network, responsively with excess of positive voltage above said negative bias-voltage, including inductive coupling means coupling said diode-circuit means with said phase-shifting network, and a second coupling means including a thermionic conductance means coupling said diode-circuit means with said phase-shifting network for reflex-control of voltages upon said phase-shifting network.

20. In combination with the structure of claim 19, resonator-means including capacitance means coupled with said inductance means for tuning with a frequency of said phase-shifting network, for controlling the phase of voltages upon said coupling means.

21. A diode modulator device for modifying voltages upon a phase-shifting network, said device having a diode-rectifying means including a cathode with a diode-anode, diode-circuit means connected between said cathode and diode-anode serially including a resonator means and a negative bias-voltage control means for controlling the amount of negative bias-voltage of said diode-anode relative to said cathode, said resonator

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means being resonant with a frequency of said network; energizing means for impulsively sustaining oscillations in said resonator means with energy from said phase-shifting network responsive to excess of positive voltage above said negative bias-voltage, including a first coupling means coupling said diode-circuit means with said network, and a second coupling means including a thermionic conductance means coupling said diode-circuit means with said phase-shifting network, for reflex-control of the phase and magnitude of voltages upon said network.

EDWARD H. LANGE.

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