Nov. 11, 1941. K. RATH 2,262,407

VARIABLE FREQUENCY RESPONSE SYSTEM

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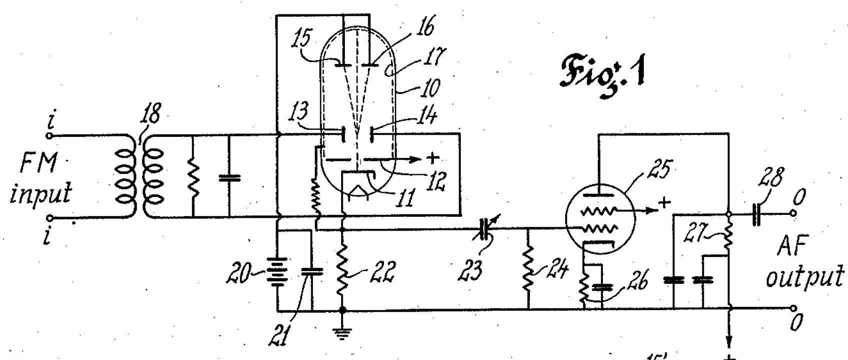

Fig. 1

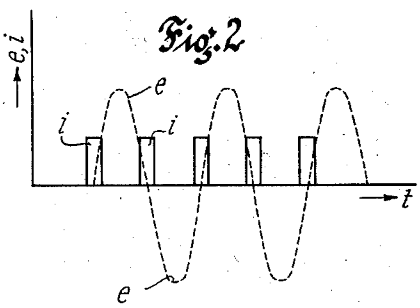

Fig. 2

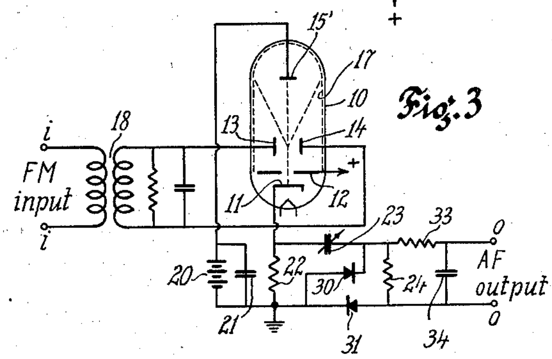

Fig. 3

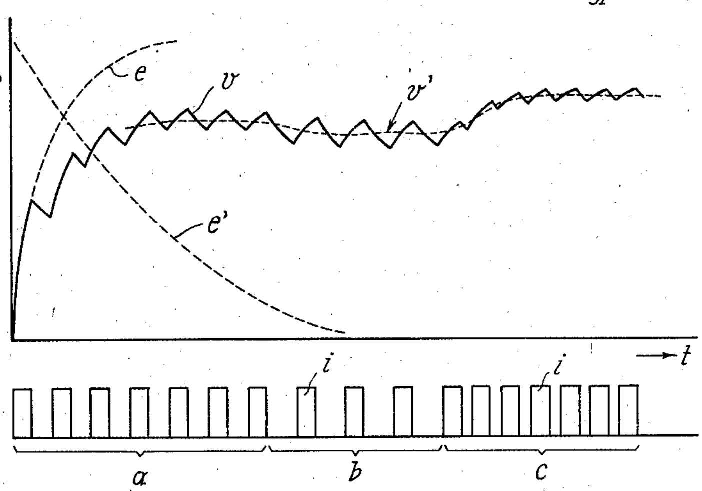

Fig. 4a

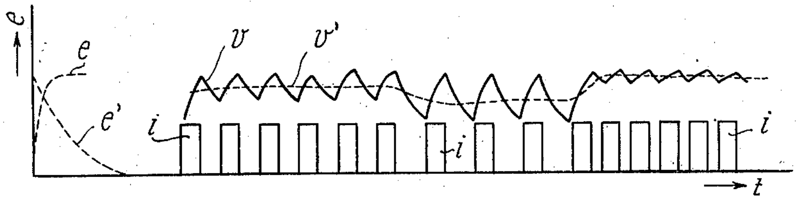

Fig. 4b

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Fig. 5

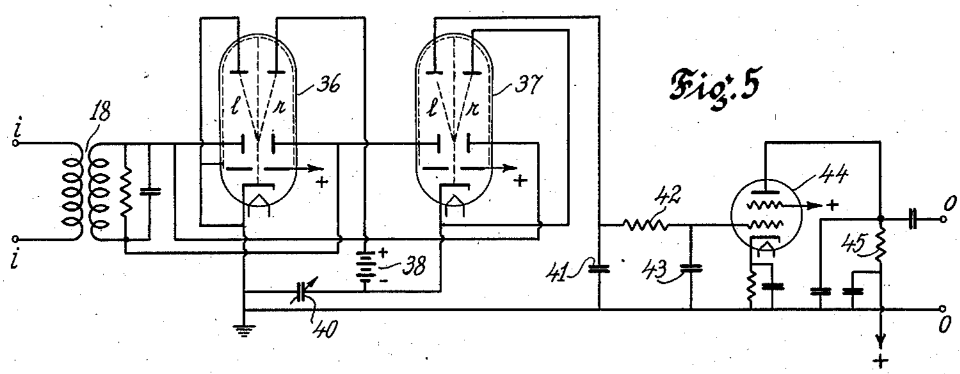


Fig. 6

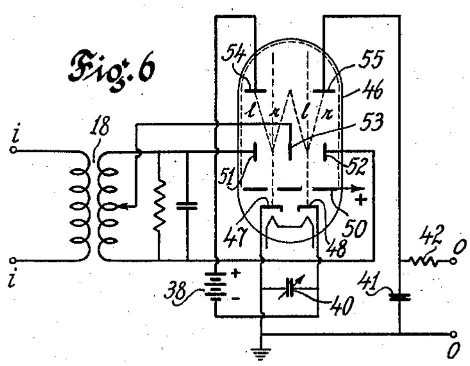


Fig. 7

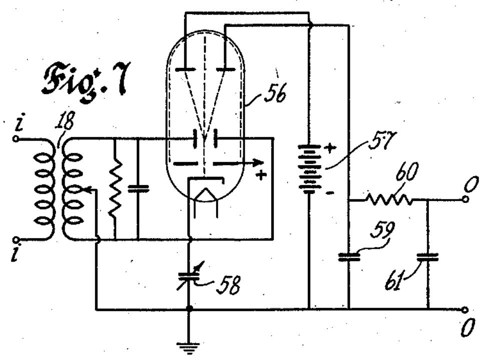
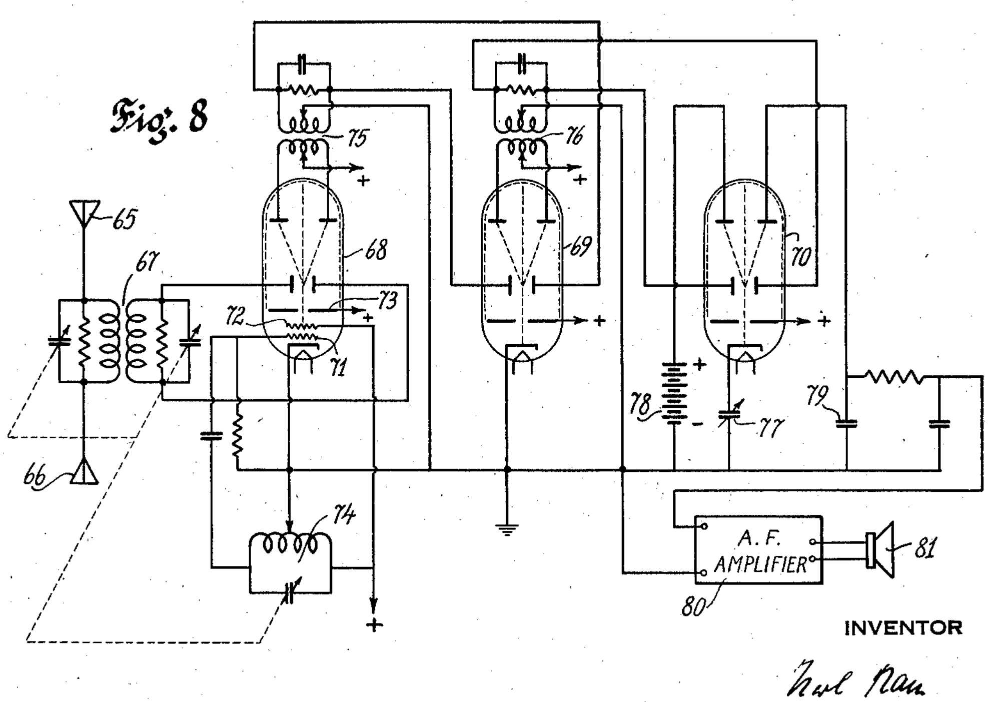


Fig. 8



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VARIABLE FREQUENCY RESPONSE SYSTEM

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Application March 17, 1941, Serial No. 383,698

9 Claims. (Cl. 250—27)

This application is a continuation-in-part carved out from U. S. application Ser. No. 367,180, filed November 26, 1940, entitled "Frequency modulation system."

The present invention is concerned with a variable frequency response system or frequency meter and methods of operating the same serving to convert frequency changes of electrical energy into corresponding amplitude changes for use in various devices such as in the discriminator or detector stage of a frequency modulation receiver, in automatic frequency control circuits, in frequency monitors or indicators and numerous other devices involving the conversion of frequency changes into corresponding amplitude variations of an electric current or potential.

An object of the invention is to provide a simple and efficient frequency converter or discriminator of the impulse counting or integrating type involving the alternate charge and discharge of an electrical condenser at a rate proportional to the frequency to be converted, whereby the average charge of said condenser will vary as a function of the instantaneous frequency and may be utilized to operate a suitable indicator or translating device, if desired after additional amplification in a low frequency amplifier such as in the case of a frequency modulation radio receiver.

A further object is to provide a highly stable and sensitive frequency discriminator wherein the output circuit is substantially decoupled from the input circuit resulting in a complete absence of interaction and consequent distortion of the converted or demodulated current as is the case in discriminators of known type involving the use of tuned circuits and utilizing the relative detuning between the circuits or relative phase of electrical energies as a means for translating the frequency changes into amplitude variations.

Another object is to provide a frequency discriminator utilizing one or more deflection control electron discharge tubes as a means for charging and discharging an electrical condenser, thereby enabling a close and accurate adjustment of the charge and discharge periods and resulting in a highly efficient and stable impulse counting or integrating action or translation of frequency changes into corresponding amplitude variations.

A further object is to provide a discriminator adjusted to act simultaneously as an amplitude limiter so as to be responsive substantially to frequency changes only and to eliminate disturbances and objectionable distortion of the output current caused by spurious and other amplitude modulation of the input signals in a frequency modulation receiver or equivalent electrical circuit.

These and further objects and novel aspects of the invention will become more apparent from the following detailed description taken with reference to the accompanying drawings forming part of this specification and wherein:

Figure 1 is a simple circuit diagram of a frequency meter or discriminator embodying the principles of the invention,

Figure 2 represents a graph explanatory of the function of the circuit according to Figure 1,

Figure 3 shows a modification of a discriminator of the type according to Figure 1,

Figures 4A and 4B are further theoretical diagrams illustrative of the operation of the circuits according to Figures 1 and 3, respectively,

Figure 5 is a circuit diagram of a modified discriminator circuit constructed in accordance with the invention,

Figure 6 shows a modification of the circuit of Figure 5,

Figure 7 represents a further modification of a discriminator embodying the principles of the invention, and

Figure 8 is a complete circuit diagram, partly in block form, of a frequency modulation receiver embodying a discriminator or second detector of the type proposed by the invention.

Like reference characters identify like parts throughout the different views of the drawings.

Referring more particularly to Figure 1, there is shown an electron discharge tube 10 of the deflection control type comprising a source of electrons or cathode 11, an apertured anode 12 serving to produce a concentrated beam or pencil of electrons, a pair of electrostatic deflecting plates 13 and 14, and a pair of anodes or targets 15 and 16 arranged on either side of the normal or zero axis of the electron beam. Alternating current voltage of varying frequency such as supplied by the RF or IF section of a frequency modulation (FM) radio receiver is impressed from input terminals *i—i* upon the deflecting plates 13 and 14 by way of a resonant transformer or band-pass filter 18. The latter is suitably designed to have a sufficient band width to cover the frequency variation range of the impressed signals (150 kc. according to present frequency modulation standards). In addition to or in place of the focussing anode 12 other concentrating or focussing devices well known in the art may be provided to obtain an electron beam of desired concentration and a cross-section. The anodes 15 and 16 are connected to the cathode through a source of high potential 20 by-passed by a condenser 21 and a load resistance 22, which latter may have its end remote from the cathode connected to ground or any other zero reference point of the system. Resistance 22 is shunted by a preferably adjustable condenser 23 in series with a further resistance 24. The latter is coupled to the input control grid and cathode of a low frequency or audio amplifier tube 25 provided with a standard condenser shunted grid biasing resistance 26 inserted in the lead to its cathode. The plate circuit of tube 25 includes a suitable load impedance, in the example shown a low-pass filter comprising a series resistor 27 and a pair of by-pass condensers.

The operation of Figure 1 will now be described with reference to Figure 2:

If the targets 15 and 16 are arranged sufficiently close and have a width which is small compared with the maximum deflection or excursion of the electron beam as effected by the impressed input voltage e, short current impulses i will be produced in the output circuit charging the condenser 23 by way of resistor 24. During the interval between the impulses i, condenser 23 is discharged through resistors 22 and 24 in series, whereby the periodic alternate charge and discharge will result in an average voltage developed across resistor 24 which will vary substantially in proportion to the frequency of the impulses i, that is in turn in proportion to the frequency of the impressed input potential. In case of a frequency modulated input signal there is thus developed a voltage at modulating frequency across resistor 24 which is further amplified by the tube 25. The amplified demodulated energy may be derived from load resistor 27 in the plate circuit of tube 25 in any suitable manner such as by way of coupling condenser 28 and impressed upon a further amplifier or output device such as a loud speaker connected to the output terminals o—o. The inner surface of tube 10, if made of glass, is advantageously coated with a metallic layer 17 connected to the cathode or ground preferably through a high ohmic resistance as shown to prevent the effect of objectionable wall charges on the operation and stability of the tube.

Referring to Figure 3 there is shown a circuit similar to Figure 1 wherein however condenser 23 is charged substantially instantaneously to the full voltage of the source 20 during the impulse periods and subsequently discharged through resistor 24 by the provision of a pair of uni-lateral conducting paths provided by rectifiers 30 and 31 which may be of any suitable type such as diode or dry rectifiers, respectively. To this end condenser 23 is shunted across resistor 22 in series with rectifier 30 and the output or discharge resistor 24 is shunted across the rectifier 30 in series with the rectifier 31. If both rectifiers are poled in an opposite sense as shown, it is seen that during the impulse periods i condenser 23 is substantially instantaneously charged by way of rectifier 30 to the full voltage and subsequently discharged through resistor 24 by way of rectifier 31. In Figure 3 the two targets 15 and 16 as shown in Figure 1 are replaced by a single target 15′ located in the central or zero axis of the electron beam and designed to produce charging impulses i according to Figure 2 at the instant of passage through zero of the impressed input potential e.

The operation of the invention will be further understood by reference to Figures 4A and 4B. Figure 4A shows the operation preferably used in case of Figure 1, wherein the condenser 23, discharge resistor 22, output resistor 24, and the length or duration of the impulses i (proper size and spacing of the targets 15 and 16 or a single target 15′ as shown in Figure 3 in relation to the maximum excursion of the electron beam) are correlated in such a manner that condenser 23 is never charged to the full or maximum voltage supplied by the source 20, whereby an average voltage is developed across resistor 24 varying substantially proportionately to the instantaneous frequency of the impressed input voltage. Condenser 23 is charged according to an exponential curve e as shown in Figure 4A and discharged according to an exponential curve e' at a much lesser rate as explained hereinabove. If the duration of the impulses i and their relation to the maximum excursion of the electron beam is properly chosen, the charge and discharge curve of the condenser 23 will assume a zig-zag line v as shown in the drawing resulting in an average voltage developed by resistor 24 as shown at v'. In the example illustrated, it has been assumed that a voltage of medium frequency is applied during the period a changing into a lower frequency during the period b and assuming a higher frequency during the period c. As a result, the average output voltage v' will vary from a mean value to a lower and higher value substantially in proportion to the instantaneous input frequency. As pointed out above, this operation is dependent on the condition that the length of the impulses i is substantially constant and independent of the frequency, whereby only the spacing intervals between successive impulses will vary as a function of the instantaneous input frequency impressed upon the deflecting plates 13—14. This condition can be easily insured by designing the target electrodes in such a manner that the time of contact with the electron beam is a fraction only of the total cycle or excursion of the electron beam from its zero or central position.

Figure 4B shows an operating diagram preferably used in case of Figure 3 wherein the condenser 23 is charged to substantially the full voltage during each impulse period i and discharged to varying lower potentials during the intervening periods whose duration varies as a function of the frequency, whereby again in turn an average output voltage v' is obtained in an analogous manner to Figure 3.

Referring to Figure 5, there is shown a modified frequency discriminator acting also as an amplitude limiter and embodying a pair of deflection control tubes in accordance with the invention. According to this exemplification there are provided a pair of deflection control tubes 36 and 37 of substantially similar construction to that described hereinbefore. A frequency modulated input voltage is impressed by way of band-pass filter 18 upon the deflecting systems of both tubes, in the example shown connected in parallel, whereby during the opposite half cycles of the input frequency the electron beams of the tubes will assume left and right positions as shown at l and r, respectively. In the example illustrated the right hand target of the tube 36 is connected to the cathode of tube 37 through a high tension or output current source 38, while the left hand target of tube 37 is connected to the grounded cathode of tube 36 through an output or discharge condenser 41. The cathodes of both tubes are further connected through a charging condenser 40. The remaining unused or idle targets of the tubes are preferably connected to the respective cathodes as shown, if desirable in series with high ohmic resistors as shown in Figure 1, to prevent interference with the proper function of the tubes, or the idle targets may be disconnected entirely from any parts of the system.

The operation of this system is as follows: In the position of the electron beams shown at *r* condenser 40 will be connected to the source 38 by way of the electron beam of tube 36 forming a return path, whereby the condenser will be charged to the voltage supplied by the source 38. During the opposite half cycle of the impressed signal voltage when the electron beams are in a position shown at *l* the source 38 will be disconnected from the condenser 40 and the latter will be connected upon the output or discharge condenser 41 by way of the electron beam of tube 37. Preferably, the design and adjustment of the tubes are such that the full cross-sectional area of the electron beams will be impinged upon the targets at a predetermined fraction of the maximum or peak amplitudes of the impressed signal voltage, whereby the tubes will additionally function as amplitude clipping or limiting devices and remove any spurious or other undesirable amplitude modulation in the manner described in detail in the above mentioned parent application.

In this manner condenser 41 will be sequentially charged by short voltage impulses of equal amplitude determined by the limiting or clipping action of the tube, the sequence or number of charging impulses per second being proportional to the instantaneous frequency of the input signals impressed upon the deflecting systems, in such a manner that the system will act as an impulse counter in a manner similar to the preceding circuits. The average charge of or voltage developed by the condenser 41 will therefore vary in accordance with the instantaneous input frequency, that is in turn with the momentary amplitude of the audio or any other modulating signal to be detected. This voltage is impressed upon the audio amplifier 44, in the example shown by way of a low-pass filter comprising series resistor 42 and by-pass condenser 43, whereby amplified audio energy may be derived from the output terminals *o—o* for further amplification or utilization in a suitable output device.

Referring to Figure 6, there is shown an arrangement similar to Figure 5 utilizing a composite deflector-discriminator and limiting tube in place of two separate tubes provided in Figure 5. The composite tube 46 according to this modification comprises a pair of cathodes 47 and 48, a common focussing anode 50 provided with two apertures opposite to said cathodes in addition to any further focussing or concentrating elements known per se which may be provided for obtaining a pair of sharply focussed electron beams or pencils. There is further shown a composite deflecting system comprising three deflecting plates 51, 52 and 53 arranged side by side in spaced relation in such a manner that either of the electron beams will pass between two adjacent deflecting plates. The central plate 53 is connected to the mid tap or center point of the secondary winding of the input transformer 18 whose opposed outer ends are connected each to one of the outer deflecting plates 51 and 52, respectively. In this manner the electron beams will assume positions as shown at *r* and *l* during the opposite half cycles of the impressed signal voltage, thereby alternately striking the targets 54 and 55 and charging condenser 40 and subsequently discharging it upon condenser 41 in a manner substantially similar to that described in connection with Figure 5. The inner surface of tube 46 is advantageously covered with a metal coating connected to ground through a high ohmic resistor as shown in and serving a purpose similar to that according to Figure 1 and having the additional function in Fig. 6 of preventing a short circuiting of the charging condenser 40 by the electron beams when striking the metal coating.

Figure 7 shows a simplified discriminator or frequency meter embodying the principle of the invention. A two-target deflector tube 56 of the same type as shown in the preceding illustrations has its input or deflection control electrodes excited from a suitable input voltage by way of band-pass filter 18. The cathode is grounded through charging condenser 58, while the targets are grounded through the high potential source 57 and discharge condenser 59, respectively. In this manner condenser 58 will be charged by the source 57 intermittently at a rate proportional to the input signal frequency and as a result thereof develop an average output voltage proportional to the frequency changes. This output voltage is impressed upon a subsequent circuit or output device by way of low-pass filter comprising a series resistor 60 and by-pass condenser 61 in a manner understood from the foregoing.

Referring to Figure 8 there is shown a circuit diagram partly in block form of a complete frequency modulation receiver embodying a deflector type discriminator or second detector of the type proposed by the invention. Frequency modulated radio signals intercepted by a suitable antenna such as a dipole 65—66 are impressed by way of a band-pass filter 67 upon the deflection control plates of a first deflector-mixer tube 68 of the type described in detail in my copending application Ser. No. 380,103, filed February 24, 1941, entitled "Electronic modulator." As described in said application, the tube 68 includes a pair of grid electrodes 71 and 72 located between the cathode and the focussing anode 73 or other focussing or beam generating arrangement. Grid 72 is operated as an anode and designed to act as a secondary electron emitter to produce a virtual cathode serving as a source for the electron beam. Item 74 is a resonant circuit connected to the electrodes 71 and 72 in self-generating arrangement to maintain the electron discharge at a constant oscillation at a frequency determined by the tuning frequency of the circuit 74. By reason of this initial control of the intensity of the electron beam in accordance with the oscillating frequency and by the subsequent additional control by the deflection potential in accordance with the signal frequency, a potential of intermediate frequency equal to the difference between the signalling and local oscillating frequencies will be developed in the output circuit by the band-pass filter 75 tuned to the intermediate frequency and connected to the targets of the tube in push-pull in the manner described in said copending application. The intermediate frequency signals are impressed upon the deflecting plates of a further deflection control tube 69 serving as an intermediate frequency amplifier and limiter. The amplified intermediate frequency signals supplied by tube 69 by way of intermediate frequency transformer 76 are impressed upon the deflecting plates of a frequency converter or discriminator tube 70 of substantially the same type as shown in Figure 7 comprising charging condenser 77, high potential source or battery 78 and discharge condenser 79. The demodulated or audio voltage supplied by the discriminator stage is impressed upon an audio frequency amplifier 80 of known design to produce output energy of sufficient amplitude for operating a suitable output device such as a loud speaker 81.

It will be evident from the foregoing that the invention is not limited to the specific steps as well as circuits and arrangements of parts and details shown and described herein for illustration and that numerous variations and modifications may be resorted to differing in size, shape, degree, etc., from the specific details shown but coming within the broader scope and spirit of the invention as defined in the appended claims. The specification and drawings are accordingly to be regarded in an illustrative rather than a limiting sense.

I claim:

1. A frequency discriminator comprising an electron discharge tube provided with a cathode and means for producing a concentrated electron beam, a plurality of target electrodes, and a deflecting arrangement, a source supplying alternating current input energy of varying frequency, means including circuit connections from said source to said deflecting arrangement for alternately sweeping said beam over said targets at the rate of the input frequency, a circuit including a first condenser and a source of charging potential connected to said cathode and one of said target electrodes for intermittently charging said condenser through said electron beam, and a further condenser connected to another of said targets and arranged to be charged from said first condenser between the charging periods of the latter.

2. A frequency discriminator comprising an electron discharge tube provided with a cathode and means for producing a concentrated electron beam, a pair of target electrodes and a pair of electrostatic deflecting plates for sweeping said beam over said targets, a source supplying alternating current input energy of varying frequency, means including circuit connections from said source to said deflecting plates for alternately sweeping said beam over said targets at the rate of the input frequency, a circuit including a first condenser and a source of charging potential connected to said cathode and one of said targets for intermittently charging said condenser through said electron beam, and a further condenser connected to the other target and arranged to be charged from said first condenser through said electron beam between the charging periods of the said first condenser.

3. A frequency discriminator comprising an electron discharge tube provided with a cathode and means for producing a concentrated electron beam, a plurality of target electrodes and a deflecting arrangement, a source supplying alternating current input energy of varying frequency, means including circuit connections from said source to said deflecting arrangement for alternately sweeping said beam over said targets at the rate of the input frequency, a circuit including a first condenser and a source of substantially constant charging potential connected to said cathode and one of said targets for intermittently charging said condenser through said electron beam, and a further condenser connected to another of said targets and arranged to be charged by said first condenser through said electron beam between the charging periods of said first condenser, the size of said targets being related to the cross-section and the maximum excursion of said beam such that at least said first condenser is charged during substantially equal periods substantially independently of the input frequency.

4. A frequency discriminator comprising an electron discharge tube provided with a cathode and means for producing a concentrated electron beam, a plurality of target electrodes and a deflecting arrangement, a source of alternating current input energy of varying frequency, means including circuit connections from said source to said deflecting arrangement for periodically sweeping said beam over said targets, a circuit including a first condenser and a source of substantially constant charging potential connected to said cathode and one of said targets, a second condenser connected to another of said targets, whereby said first condenser is charged by said source through said electron beam during a fraction of one half cycle and is discharged upon said second condenser through said beam during the opposite half cycle of the input frequency, and an output circuit connected to said second condenser.

5. A frequency discriminator comprising an input circuit traversed by alternating current having a varying frequency, a first condenser, a source of substantially constant charging potential, a second condenser, electron beam discharge means including target means connected to said condensers and said source, deflecting means coupled with said circuit for effecting a periodic beam deflection in accordance with the input frequency to charge said first condenser during a fraction of one half cycle and to discharge it upon said second condenser during the opposite half cycle of the input frequency, and an output circuit connected to said discharge condenser.

6. In a frequency discriminator, means for producing a pair of electron beams, deflecting means for each of said electron beams, a first target arranged to be impinged by the first beam and a second target arranged to be impinged by the second beam, means for impressing alternating signal energy of varying frequency upon both said deflecting arrangements to cause said electron beams to alternately strike said first and second targets during the positive and negative half cycles, respectively, of the signal frequency, a first condenser connected between said cathodes, a source of positive potential connected between said first target and said second cathode and a further condenser connected between said second target and said first cathode, whereby said first condenser is charged by said source during a fraction of one half cycle and discharged upon said second condenser during the opposite half cycle of the impressed signal frequency, and an output circuit connected to said second condenser.

7. A frequency discriminator comprising an electron discharge device provided with a cathode and means to produce a concentrated electron beam, a pair of target electrodes and a deflecting arrangement, a circuit traversed by alternating signal current of varying frequency, means including circuit connections from said circuit to said deflecting arrangement for alternately

sweeping said beam over said targets in accordance with the signal frequency, a source of substantially constant charging potential having its positive pole connected to one of said targets, a first condenser connected between said cathode and the negative pole of said source, a second condenser connected between the other target and the negative pole of said source, and an output circuit connected to said second condenser.

8. An arrangement for converting electrical input energy of varying frequency into energy of corresponding amplitude comprising a condenser, a source of substantially constant charging potential, an electron beam discharge device including target means connected to said condenser and said source, electron beam deflecting means excited by said input energy for periodically closing and opening the circuits connected to said target means in accordance with the input frequency, thereby to alternately charge and discharge said condenser during a fraction of one half cycle and during the opposite half cycle, respectively, of the input frequency, and means for utilizing the average discharge current of said condenser.

9. An arrangement for converting electrical input energy of varying frequency into energy of corresponding amplitude comprising a condenser, a source of substantially constant charging potential, an electron beam discharge device including a pair of targets connected to said condenser and said source, beam deflecting means excited by said input energy for periodically closing and opening the circuits connected to said targets in accordance with the input frequency, thereby to alternately charge and discharge said condenser by way of the electron beam during a fraction of one half cycle and during the opposite half cycle, respectively, of the input frequency, and means for utilizing the average discharge current of said condenser.

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