May 13, 1941. I. ZAKARIAS 2,241,569

VARIABLE-FREQUENCY RESPONSE CIRCUIT

Filed April 16, 1940

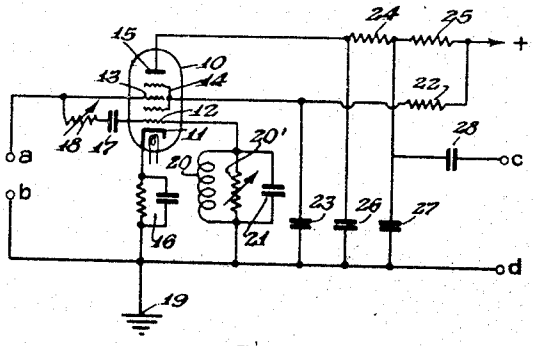


FIG.1.

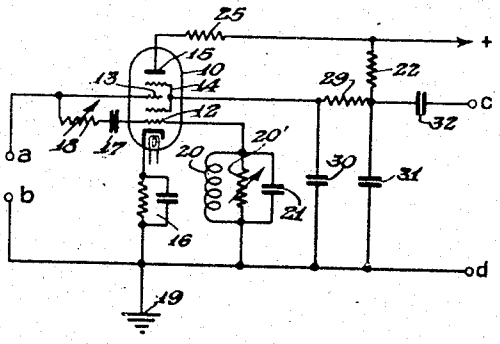


FIG.2.

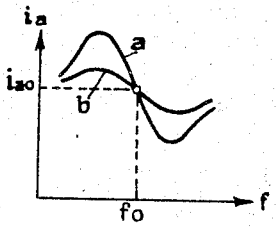


FIG.3.

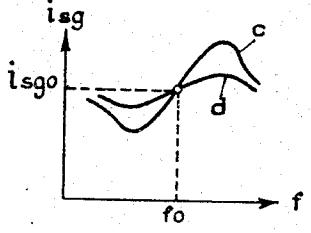


FIG.4.

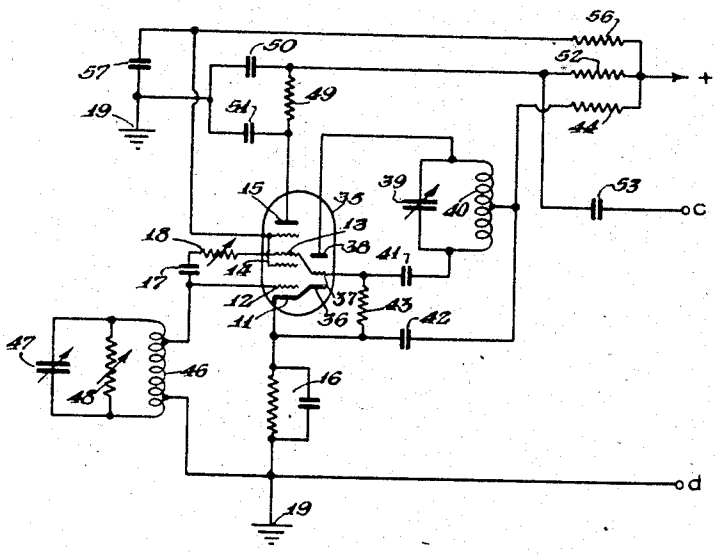


FIG.5.

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VARIABLE FREQUENCY RESPONSE CIRCUIT

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Application April 16, 1940, Serial No. 329,857
In Hungary May 6, 1939

8 Claims. (Cl. 250—20)

The present invention relates to frequency variation response circuits for converting a variable frequency, including both the frequency of an alternating current or potential and the natural or tuning frequency of a resonant circuit, into energy having an amplitude varying proportionately to said frequency variations.

More particularly the invention relates to frequency variation response circuits of the type disclosed in my copending application Serial No. 146,180, filed June 3, 1937 entitled "Frequency variation response circuit," now Patent No. 2,208,091, comprising substantially an electron discharge tube having at least two control electrodes or grids for controlling the electron space current passing from the cathode to the anode of the tube. Means are provided whereby an alternating, such as a high frequency potential impressed upon the first grid near the cathode causing a corresponding variation or modulation of the normally steady electron space current will cause a potential at the frequency of the impressed potential to be induced upon the second grid by reactive coupling with the electron current known as space charge or electron coupling as distinguished from the ordinary physical couplings by means of an inductive, capacitative, or resistive impedance. Such an electron coupling may be obtained by providing a positively biased screen between the control grids causing a concentrated electron space charge or "virtual" cathode to be set up near the second control grid and resulting in a capacitative coupling of the latter with the space current fluctuations.

According to said copending application a tuned circuit is connected between the second grid and cathode whereby the phase of the induced potential on the second grid due to space charge coupling with the electron current varies in either direction from a normal quadrature phase relation, when said tuned circuit is in resonance with the impressed potential on the first grid, proportionately to the relative frequency departure of the impressed potential from the frequency to which said tuned circuit is resonant. By mutual intermodulation of the relatively phase shifted potentials on the grids there is developed in this manner in the output current of the tube a component having an amplitude varying proportionately to the relative frequency departure of the impressed potential from the frequency to which said tuned circuit is resonant. This component may be segregated from the output current by the aid of a suitable coupling impedance or network and applied to a desired utilization circuit such an an audio frequency amplifier followed by a loud speaker in the case of a frequency modulation receiver, or to an electrically controlled tuning element of the local oscillator in a superheterodyne receiver if the circuit is used as a discriminator in an automatic frequency control system embodied in a radio receiver in a manner well understood by those skilled in the art.

An object of the present invention is the provision of an improved frequency variation response circuit of the above type adapted to stabilize and enhance the dependability of the frequency conversion.

Other objects and advantages of the invention will become more apparent as the following description proceeds taken with reference to the accompanying drawing forming part of this specification, and wherein:

Figure 1 is a diagram of a simple frequency variation response circuit according to the invention,

Figure 2 is a circuit diagram showing a modification of Figure 1,

Figures 3 and 4 are characteristic curves explanatory of the function of the invention,

Figure 5 is a diagram showing a further modification especially suited for converting variations of the natural or tuning frequency of a resonant circuit.

Like reference numerals identify like parts in the different views of the drawing.

The space charge coupling utilized in systems of the above character is by its very nature a uni-lateral capacitative coupling i. e. a coupling directed from the first grid near the cathode to the second control grid shunted to cathode through the tuned circuit having a negative sense compared with an ordinary capacitative coupling effected by means of a physical condenser or capacity element. The value of the space charge coupling in electron tubes is of the order of about .1 to 10 mmfd.; i. e. sufficient to afford efficient conversion or demodulation of a varying frequency signal as disclosed in the above mentioned copending application.

A disadvantage of the system disclosed in said application which may be objectionable in certain cases and tend to impair the dependability and stability of the system is the fact that undesirable reaction between the grids due to the inter-electrode capacity between the grids (of the order of .2 mmfd.) may result in distortions of the output signals and other disadvantages.

According to the present invention this diffi-

culty is substantially eliminated by the provision of an ordinary, bi-lateral or mutual capacity coupling between the control grids in the form of a condenser connecting the grids and adapted to neutralize the uni-lateral space charge coupling between the grids resulting in a new uni-lateral coupling directed opposite to the original space charge coupling. In certain cases, especially for short waves, a resistance is advantageously placed in series with the coupling condenser to equalize the effect of the transit time of the electrons passing from one grid to the other. Thus, if the space charge coupling is neutralized in the above described manner, the new uni-lateral coupling produced between the grids in a sense opposite to the original space charge coupling will be in a direction from the second grid towards the first grid located near the cathode.

According to the present invention this new uni-lateral coupling is utilized for effecting a frequency conversion by applying the signal potential to the second grid remote from the cathode and providing a tuned circuit connected to the first grid near the cathode or in other words, by inter-changing the circuits connected to the control grids in the arrangement disclosed in the copending application. In this manner a pure uni-lateral coupling is obtained between the grids substantially without objectionable interaction, as the inter-electrode capacity between the grids may form a part of a neutralizing capacity, thus resulting in increased operational stability and dependability of the system.

Referring to Figure 1, item 10 represents an electron tube comprising a cathode 11 followed in succession by a first control grid 12 and a second control grid 13, a screen grid 14 arranged between the grids 12 and 13, and a plate or anode 15. Item 16 is a biasing network comprising a resistance by-passed by a condenser connected in the return lead from the cathode 11 to ground 19 or any other zero potential point of the system according to standard practice.

If in a tube of this type a signal potential is impressed upon the grid 12 near the cathode, a concentrated variable space charge or "virtual cathode" is produced near the control grid 13 resulting in a negative capacitative or space charge coupling in a direction from the grid 12 to the grid 13. This negative space charge coupling according to the present invention is neutralized by a positive capacitative coupling by the provision of a condenser 17 connecting the grids 12 and 13 and preferably having a variable resistance 18 connected in series therewith for equalizing the effect of the transit time of the electrons passing from the grid 12 to grid 13, especially in the case of short waves as pointed out hereinabove. In this manner, by neutralization of the negative space charge coupling by a corresponding positive capacitative coupling, a new uni-lateral coupling is produced in the opposite direction; i. e., from the grid 13 to the grid 12. This phenomenon will be further understood from the following: Inasmuch as the space charge coupling from the first control grid 12 toward the second control grid 13 is uni-lateral, and the coupling by means of the condenser 17 is bi-lateral or mutual, the neutralizing of the uni-lateral space charge coupling by the bi-lateral condenser coupling will result in a new uni-lateral condenser coupling which is directed opposite to the original space charge coupling, i. e. from the second control grid 13 towards the first control grid 12. This uni-lateral coupling is utilized according to the invention to effect a frequency conversion in a manner described in the following.

The input alternating potential such as a high frequency potential is applied by way of input terminals *a*—*b* to the grid 13 and cathode 11. A tuned circuit comprising an inductance coil 20 shunted by a condenser 21 and a variable resistance 20' is connected between the grid 12 and ground 19, whereby the potential induced in the grid 12 by the input potential on the grid 13 will have a phase varying in dependence upon the relative frequency departure of said impressed potential from the tuning frequency to which the circuit 20—21 is resonant. Thus, assuming that the input potential is a frequency modulated signal received from a frequency modulation broadcast transmitter and that the circuit 20—21 is resonant to the carrier frequency of this signal, the phase of the potential induced on the grid 12 by the carrier frequency will be in quadrature to the phase of the input signal on the grid 13 due to the capacitative character of the space charge coupling, and will vary in either direction from this normal phase relation proportionately to the frequency deviation of the input signal with respect to the carrier frequency.

As a result, there is produced in the output or plate circuit of the tube 10 by mutual inter-modulation of the potentials on the grids 12 and 13, a component varying in sign and magnitude in proportion to the relative phase departure from a normal quadrature phase relation between the potentials on the grids; i. e., in turn in proportion to the frequency variations of the input signal. Thus, for the carrier frequency the potentials on the grids 12 and 13 will be in quadrature resulting in a zero inter-modulation product; i. e., the anode current will be equal to its normal steady value. If the input frequency increases above or decreases below the resonant frequency of the circuit 20—21, the relative phase of the grid potentials will vary accordingly in respect to the normal quadrature phase relation, resulting in an increase or decrease of the steady inter-modulation current in the output circuit as shown by curve *a* in Figure 3. In the latter, the output current i_a is plotted as a function of the input frequency *f* impressed upon the grid and i_{ao} represents the steady normal plate current for the unmodulated or carrier frequency f_o. Curve *b* shows the same relation if the damping of the tuned circuit 20—21 is increased such as by decreasing the shunt resistance 20'. As is seen, the steepness of the curves *a* and *b* at opposite sides from the frequency f_o determines the amplification or conversion efficiency which may be controlled by adjusting the resistance 20' to suit existing requirements. The frequency responsive output current may be extracted or segregated in any desired manner such as by means of a filter in the plate circuit comprising a series resistance 24 and shunting condensers 26 and 27 and applied to a subsequent utilization circuit by way of output terminals *c*—*d* by the aid of a coupling arrangement comprising in the example shown a coupling impedance 25 in series with the resistance 24 and a coupling condenser 28. The screen grid 14 is connected to the plus terminal of the high potential source supplying the electron space current and indicated by plus sign through a potential drop resistance 22 and is by-passed to ground by a condenser 23 in accordance with standard practice.

In addition to the plate current variations as shown at *a* and *b* in Figure 3, similar variations but in an opposite sense occur in the screen grid current as shown at *c* and *d*, respectively, in Figure 4, wherein the screen grid current i_{sg} is plotted as a function of the frequency *f* of the impressed input potential and i_{sgo} represents the normal screen grid current for the input (carrier) frequency f_o. According to a further modification of the invention the screen grid current is utilized as the output or demodulated current as shown in Figure 2 which differs from Figure 1 merely by the provision of a low-pass filter 29—30—31 in the screen grid circuit and a coupling of the output terminals *c*—*d* with the screen grid by means of the coupling impedance 22 and coupling condenser 32.

According to a further modification, the circuits described in Figures 1 and 2 may serve for converting the tuning frequency of the resonant circuit in which case the input potential impressed by way of terminals *a*—*b* is of constant and fixed frequency and the resonant frequency of the circuit 20—21 is varied such as by varying the inductance 20 or the condenser 21. The latter may be a condenser microphone or any other mechanically moving element adapted to affect the tuning capacity of the circuit, whereby capacity variations or small mechanical movements may be directly translated into corresponding amplitude variations of electric current supplied from the output terminals *c*—*d* in a manner well understood from the above.

A simplified arrangement of the latter type for converting variations of inductance or capacity is shown in Figure 5. In the latter, item 35 is a multi-function electron tube comprising a hexode and triode unit mounted within the same envelope. The hexode unit 11—15 is substantially similar to that shown in Figures 1 and 2, while the triode comprises a section 36 of the cathode 11, a control grid 37 and a plate 38. The triode section of the tube serves to produce an auxiliary oscillation for which purpose there is provided a tuned circuit comprising an inductance coil 40 shunted by a condenser 39 having one end connected to the plate 38 and having its other end coupled to the grid 37 through a condenser 41. A tap point of the inductance 40 is connected on the one hand to the plus terminal of a high potential source in series with a voltage drop resistance 44 and on the other hand to the cathode by way of coupling condenser 42. A grid leak 43 is connected between the grid 37 and the cathode to produce steady biasing potential for the grid 37. In this manner, sustained oscillations will be generated in the circuit 39—40 which are impressed upon the input grid 13 of the hexode section such as by directly internally connecting grid 37 of the triode section with the grid 13 of the hexode section. A resonant circuit comprising an induction coil 46 shunted by a condenser 47 and variable resistance 48 is connected between the grid 12 and ground 19 and a neutralizing condenser 17 in series with a variable resistance 18 is connected between the input grid 13 and the grid 12 in a manner substantially similar to that described hereinbefore. 49—50—51 is a filter in the output circuit, 52 a coupling resistance, 53 a coupling condenser, and 56 and 57 a further voltage drop resistance and shunting condenser, respectively, to supply proper positive potential for the screen grid 14. In operation, the oscillating potential on the grid 13 will cause a similar potential to be developed upon the grid 12 at varying phase depending upon the relative frequency departure of the resonant frequency of the tuned circuit 46—47—48 from the oscillating frequency determined by the tuning adjustment of the circuit 39—40. If the tuning of the latter is maintained at a fixed value, variations of the natural frequency of the circuit 46—47—48 as caused by variations of the inductance 46 or the condenser 47 are converted directly into current of varying amplitude obtained from output terminals *c*—*d*.

As will be evident from the foregoing the invention has many uses, primarily as a demodulator for frequency modulated radio signals or as a discriminator in automatic frequency control arrangements embodied in radio receivers. Furthermore, the inventive circuit may advantageously be used in numerous electronic control systems involving the problem of converting variations of an inductance, capacity, or resistance into corresponding electric current variations. In the case of a variable resistance 48 it is seen that a corresponding variation of the output current is obtained due to the change in the conversion constant or steepness of the curves *a* and *b* as shown in Figures 3 and 4.

In place of a parallel tuned resonant circuit connected between the grid 12 and ground, a series tuned circuit or any other resonant network may be employed without departing from the spirit of the invention.

Furthermore, it is understood that any suitable type of electron discharge tube may be employed for the purpose of the invention adapted to produce a space charge coupling and differing in other details from the tubes shown in the drawing for purpose of illustration.

Accordingly, it is understood that the invention is not limited to the specific details and arrangements of parts as well as circuits shown and disclosed herein for illustration, but that the novel principle and underlying thought of the invention are susceptible of numerous variations and modifications coming within the broader scope and spirit of the invention as defined in the ensuing claims. The specification and drawing are to be regarded in an illustrative rather than in a limiting sense.

I claim:

1. In a frequency variation response circuit, an electron discharge tube comprising a cathode and an anode, a first control grid near the cathode, and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said grids to substantially neutralize said space charge coupling, means for impressing an alternating potential upon said second control grid, resonant impedance means connected to said first control grid and cathode, the relative frequency of the impressed potential with respect to the resonant frequency of said impedance means being varied, an output circuit connected to said anode, and means operatively associated with said output circuit for developing output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said impedance means.

2. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control near the cathode, and a second control grid, a screen grid located between said first and second control grids, means for maintaining said screen grid at a positive

potential with respect to said cathode to produce a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said grids to substantially neutralize said space charge coupling, means for impressing an alternating potential upon said second control grid, resonant impedance means connected to said first control grid and cathode, the relative frequency of the impressed potential with respect to the resonant frequency of said impedance means being varied, an output circuit connected to said anode, and means operatively associated with said output circuit for developing output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said impedance means.

3. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control grid near the cathode, and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said control grids to substantially neutralize said space charge coupling, means for impressing an alternating potential of varying frequency upon said second control grid and cathode, resonant impedance means tuned to a predetermined frequency connected to said first control grid and cathode, an output circuit connected to said anode, and impedance means operatively associated with said output circuit for developing output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said impedance means.

4. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control grid near the cathode and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said control grids to substantially neutralize said space charge coupling, means for impressing an alternating potential of constant frequency upon said second control grid and cathode, a tuned circuit connected to said first control grid and cathode, means for varying the resonant frequency of said tuned circuit, an output circuit connected to said anode, and impedance means operatively associated wtih said output circuit for developing output energy varying in amplitude proportionately to the relative frequency departure of said impressed potential from the frequency to which said tuned circuit is resonant.

5. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control grid near the cathode, and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, a series path comprising a condenser and a resistance connected between said control grids to provide an exterior capacitative coupling between said control grids to substantially neutralize said space charge coupling, means for impressing an alternating potential upon said second grid and cathode, resonant impedance means connected between said first control grid and cathode, the relative frequency of said impressed potential with respect to the resonant frequency of said impedance means being varied, an output circuit connected to said anode, and impedance means operatively associated with said output circuit for developing output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said impedance means.

6. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control grid near the cathode, and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said control grids to substantially neutralize said space charge coupling, means for impressing an alternating potential upon said second grid and cathode, a tuned circuit connected to said first grid and cathode, resistance means for controlling the damping of said tuned circuit, the relative frequency of said impressed potential with respect to the resonant frequency of said tuned circuit being varied, an output circuit connected to said anode, and impedance means operatively associated with said output circuit for developing output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said tuned circuit.

7. In a frequency variation response circuit, an electron discharge tube comprising a cathode, an anode, a first control grid near the cathode, and a second control grid, means for producing a space charge coupling from said first control grid towards said second control grid, exterior capacitative coupling means between said control grids to substantially neutralize said space charge coupling, means for impressing an alternating potential upon said second control grid and cathode, resonant impedance means connected to said first control grid and cathode, the relative frequency of said impressed potential with respect to the resonant frequency of said impedance means being varied, an output circuit connected to said anode, and load impedance means inserted in said output circuit adapted to develop output energy varying in amplitude proportionately to the frequency departure of said impressed potential from the resonant frequency of said impedance means.

8. The combination with a source of alternating potential and an electric circuit, of means for exciting said circuit by said alternating potential comprising an electron discharge tube having a cathode followed in the order named by a decelerating grid, an accelerating grid and a further decelerating electrode, means for maintaining said accelerating grid at a steady positive potential with respect to said cathode to normally produce a variable space charge coupling from said first decelerating grid towards said decelerating electrode, means for connecting said source to said decelerating electrode and said cathode, means for connecting said circuit to said decelerating grid and said cathode, and exterior capacitative coupling means connecting said decelerating grid and said decelerating electrode to substantially neutralize said space charge coupling whereby said circuit is excited by uni-lateral capacitative coupling by said source.

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