July 10, 1934. L. M. HULL 1,965,645

AUDION CIRCUIT

Original Filed Sept. 29, 1925

Fig. 1.

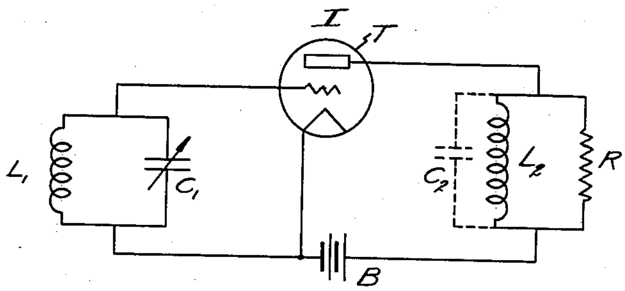



Fig. 2.

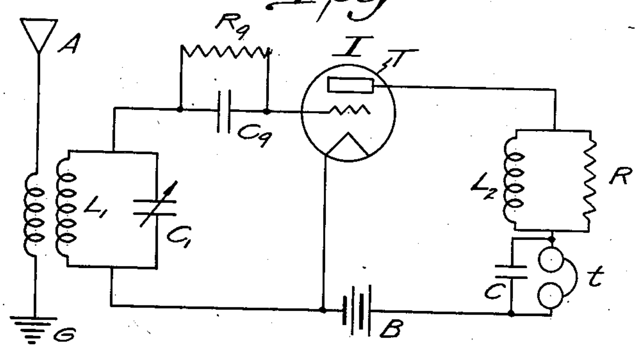
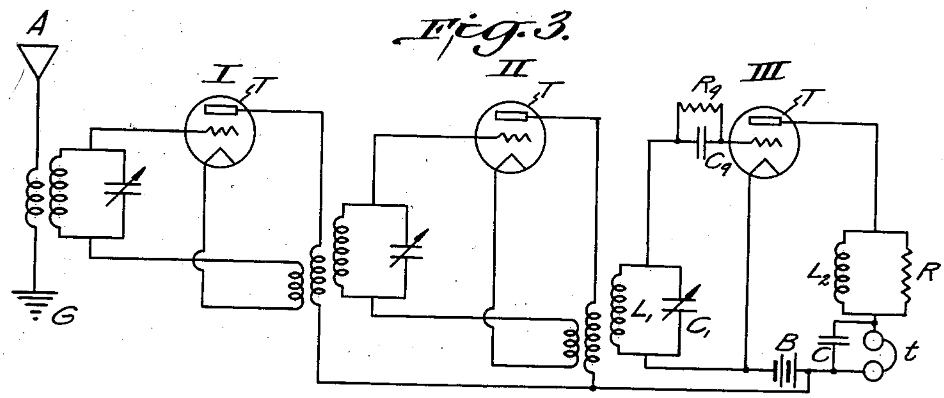



Fig. 3.

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# UNITED STATES PATENT OFFICE

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## AUDION CIRCUIT

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11 Claims. (Cl. 179—171)

This invention relates to audion circuits and particularly to such circuits adapted to the reception of radio signals. Circuits of this type in which the audion output circuit reacts upon the audion input circuit are well known. Such reaction may take place through the inherent capacities of the audion tube, and particularly through the grid-plate capacity, or through these capacities together with external circuit elements, but in any case, unless precautions are taken to prevent reaction, the plate or output circuit of the audion commonly reacts upon the grid or input circuit. If the impedance of the output circuit is predominantly inductive the currents fed back to, or reacting upon, the input circuit may be of such phase and character as to reinforce or build up the currents already present in the input circuit, over a considerable range of frequencies, thereby producing the effect commonly known as regeneration. Another way of expressing this condition is by saying that due to the reaction of the audion output circuit upon the input circuit an audion having an inductive load in the plate circuit may have a negative input conductance. (Reference: Stuart Ballantine—On the Input Impedance of the Thermionic Amplifier, Physical Review, Vol. XV, No. 5, May 1920.) Such constructive or regenerative reaction occurs only when the reactance of the plate circuit impedance is predominantly inductive, and if the reactance of this impedance is predominantly capacitive or resistive, the reaction is destructive or dissipative, increasing the apparent resistance of the input circuit.

It is well known that if the output circuit of an audion tube has a fixed inductance of such value as to produce constructive reaction or regeneration, the amount of this regeneration will be a function of frequency because the reactance of the inductance decreases with decreasing frequency. Therefore, in order to obtain substantially constant reaction or regeneration over a considerable range of frequencies it is necessary to add inductance to the audion plate circuit as the frequency decreases. This is commonly done by providing a variable inductance, such as a variometer, in the audion plate circuit, but this arrangement has certain disadvantages, notably that of requiring an additional adjustment for every change in frequency. In the case of a radio receiving or amplifying system this adjustment is often critical and difficult, and is highly undesirable.

My invention contemplates broadly the provision, in conjunction with an audion having input and output circuits, of an impedance in the output circuit the effective inductive reactance of which decreases with decreasing frequency at less than the normal rate of decrease of the inductive reactance of a substantially pure inductance. According to my invention I may produce a sensitive audion receiving circuit, I may increase the amplification of audion amplifiers over a given range of frequencies, and I may obtain all the advantages of an inductive plate-circuit load over a considerable range of frequencies, without the necessity for varying a circuit element in order to obtain the desired reaction at each frequency. I may also obtain a regenerative audion circuit in which the input circuit is adjustable or tunable while the output circuit comprises a fixed impedance, it having hitherto been necessary to adjust or tune the output circuit as well as the input circuit in order to obtain regeneration. In particular, I may obtain a substantially uniform degree of reaction of the audion output circuit upon the input circuit over a wide and pre-determined range of frequencies without the necessity for an adjustment of the output circuit inductance for varying frequency. In practice I prefer to so proportion the constants of my circuit that this range of frequencies coincides with the broadcast range. Other advantages of my invention will occur to those skilled in the art. I preferably accomplish these results by the use of a composite load in the plate circuit, this load being so designed that its effective inductive reactance does not decrease with decreasing frequency with the rapidity which is normal for the reactance of a substantially pure inductance. The load may be so proportioned that its reactance decreases more slowly than is normal with a substantially pure inductance; or so that it remains substantially constant over a pre-determined frequency range; but in the preferred form of my invention the plate circuit load is so proportioned that its effective inductive reactance actually increases with decreasing frequency.

Referring now to the drawing, Fig. 1 is a single audion stage embodying my invention. Fig. 2 is an audion detector stage embodying my invention. Fig. 3 is a cascaded audion amplifier, one stage of which embodies my invention.

I shall first describe my invention with respect to the embodiment shown in Fig. 1 in which T is a three-electrode audion tube which may have a tuned input circuit $L_1$ $C_1$, connected between the grid and filament of the tube, although any other type of input may be used, and an output circuit connected between the plate and filament of the tube. I have shown this output circuit as comprising an inductance $L_2$ shunted by a resistance R, and, for the sake of generality, a capacity $C_2$ connected in parallel with the inductance, the use of which, as an element distinct from the distributed capacity of the inductance, is optional, as explained below. $L_2$ may be a substantially pure inductance having the minimum inherent distributed capacity, or it may be an inductance having any desired distributed capacity, such as that indicated by the dotted line at $C_2$, or it may be an inductance in parallel with an external capacity $C_2$, but preferably the capacity should be such that the circuit $L_2$ $C_2$ need not be resonant to the impressed frequency but may have a natural frequency greater than this frequency. In other words, the plate-circuit load comprises two branches, one of which is a resistance and the other is a non-resonant periodic circuit which may be an inductance shunted by a capacity whose value lies between the value of distributed capacity as a minimum and the value of shunt capacity which makes the natural frequency slightly greater than any desired signal frequency, as a maximum. Any or all of the elements of this impedance may of course be variable if desired, but in the preferred form such variability is unnecessary.

I have found experimentally that with certain circuits of this type having a tuned input branch and using commercial three-electrode audions, the inductance in the plate circuit necessary to provide a maximum of reaction through the tube capacities, without producing instability or oscillation, increases approximately as the square of the wavelength of the impressed currents. According to my invention the plate circuit load comprises an inductance shunted by a resistance, the reactance of the inductance, in the preferred form, being of the same order of magnitude as the resistance. The effective inductive reactance of the composite load so formed is a function of the frequency and the elements may be so proportioned if desired that this effective inductive reactance increases with decreasing frequency. Thus by the use of the arrangement of Fig. 1 the plate circuit of the audion may be provided with a composite impedance providing an inductive load of such nature as to produce substantially maximum reaction through the tube capacities, over a considerable range of wavelengths, without adjustment of the elements of the plate circuit. In practice I have produced composite loads of which the effective inductance increases approximately as the square of the wavelength, and accordingly has such absolute magnitude over a wide wavelength range as to give a substantial approximation to the maximum allowable reaction.

The hereindescribed behavior of a composite load including a self-inductance and a resistance connected in parallel, in the audion plate or output circuit, may be explained, according to my best present information as follows: In the case of a composite impedance consisting of an inductance and a resistance in parallel, a part of the total current flows through the inductance branch and the remaining part flows through the resistance branch at any given frequency. At relatively high frequencies the reactance of the inductance branch is larger than that of the resistance, and hence the resistance carries the greater part of the total current. Therefore the resistance is the dominant factor in determining the total impedance of the composite load, and the inductive component of this impedance is small. That is, the effective inductance of the load is small. As the frequency progressively decreases the component of current flowing through the inductance branch becomes larger, since the reactance of this branch is decreasing while the resistance of the resistance branch remains substantially constant. The larger the proportion of the total current which is carried by the inductance branch the more important does the inductance become in determining the total impedance of the composite load. Accordingly the effective inductance of the composite circuit increases with decreasing frequency and the effective inductive reactance of the circuit (which is equal to the effective inductance multiplied by the angular frequency) decreases with decreasing frequency at less than the normal rate of decrease of the inductive reactance of a substantially pure inductance.

The character of the variation of the inductive reactance of the load with wavelength may be altered and to some extent governed by providing the inductance $L_2$ either with an appreciable distributed capacity such as that shown at $C_2$ in Fig. 1, or by adding an external capacity at $C_2$, in parallel with the coil $L_2$. The effect of this added capacity is to increase the slope of the curve of effective plate circuit inductance plotted against wavelength in the wavelength range immediately above the resonant wavelength of the circuit $L_2C_2$, and this may be desirable under certain conditions. The circuit $L_2C_2$ should not, however, be tuned to the impressed or received wavelength, and at present I prefer to make this circuit resonant to a wavelength equal to or less than the lowest wavelength to be received by the system.

As a specific example, suppose that signals are to be received at wavelengths falling between the limits 200 to 500 meters, and the input circuit $L_1C_1$ is accordingly adjustable to resonance within this band. I have found that by properly proportioning the resistance R, inductance $L_2$, and capacity $C_2$, I can produce, at will, strong grid-plate reaction over the upper portion of the wavelength band with negligible grid-plate reaction at the shorter wavelengths, or strong and substantially uniform grid-plate reaction over the whole wavelength band. The former condition of operation is particularly desirable when the audion tube is used as a detector with an appreciable grid current flowing. I have found, for example, with a given audion and a given input circuit, that the following combination of constants yielded strong grid-plate reaction at 500 meters and weak grid-plate reaction at 200 meters:

| | |
|---|---|
| $L_2$ | 350 microhenries |
| R | 1800 ohms |
| $C_2$ | 20 micro-microfarads |

My invention is of course not limited to these or any other particular constants.

In Fig. 2 I have illustrated another embodiment of my invention. This is a single audion detector stage in which an antenna circuit A G is coupled to the tuned input circuit $L_1C_1$. The usual grid condenser Cg and grid leak Rg may be employed. As the plate circuit load I employ a resistance R shunted by an inductance $L_2$ which may or may not have a substantial amount of distributed capacity. In the plate circuit there are also the usual B battery, B, and telephones, *t*, shunted by a suitable condenser *c*. In this arrangement the plate circuit load, comprising the parallel circuit

$L_2R$, may be proportioned in any suitable manner as described above.

Fig. 3 shows a cascaded audion amplifier in which an antenna circuit A G operates into two radio frequency stages I and II which in turn operate into a detector stage III arranged according to Fig. 2. There may of course be any number of radio frequency stages and these may, if desired, be compensated or neutralized in order to limit or prevent reaction of the plate circuit upon the input circuit. Such an arrangement of a tuned amplifier may be of especial advantage since the amplification of the stage which feeds the detector is usually lower than that of the other stage or stages, due to the losses in the grid circuit of the detector. By such an arrangement as that of Fig. 3 these losses may be diminished or counteracted and the effective amplification of the last stage may be made to equal or surpass that of the other stages.

In all the figures such usual elements as filament batteries and rheostats, B battery by-pass condensers, etc. have been omitted for the sake of simplicity. My invention is not of course limited to any of the specific embodiments or circuits herein shown.

I claim:

1. An audion stage comprising an audion tube, an input circuit adapted to be tuned over a band of frequencies, a plate circuit for said tube, and a load in said plate circuit, said plate circuit load comprising a resistance in parallel with a periodic circuit having a natural period less than that of the impressed waves.

2. An audion circuit comprising an audion tube, a tuned resonant input circuit for said tube, and an untuned output circuit for said tube, said output circuit comprising a composite impedance including resistance and inductance of such relative values that within the range through which said input circuit may be tuned the effective inductance of said impedance automatically increases with decreasing frequency.

3. A regenerative audion circuit comprising an audion tube, a tunable input circuit for said tube, and an output circuit for said tube comprising a fixed composite impedance including an inductance and a resistance connected in parallel and so proportioned as to make said circuit regenerative over a predetermined frequency range.

4. An electrical amplifier comprising an audion tube, and an input circuit and an output circuit therefor, said output circuit including a composite load comprising an inductance and a resistance connected in parallel, the reactance of said inductance being of the same order of magnitude as said resistance.

5. An audion stage comprising an audion tube and a tuned input circuit and an output circuit therefor, said output circuit including a fixed composite impedance comprising a capacity, a resistance and an inductance connected in parallel, the composite impedance being connected between anode and cathode of said tube and the parts of said impedance being so proportioned that within the frequency range over which said input circuit may be tuned the effective inductance of said impedance increases with decreasing frequency.

6. An electrical circuit comprising successively, in combination, an electrical vacuum tube amplifier stage, an electrical vacuum tube detector stage, a tuned coupling system interposed between said stages to couple said amplifier stage to said detector stage, and a fixed composite impedance connected in the output circuit of said detector stage, said composite impedance being so proportioned that the effective inductive reactance thereof decreases with decreasing frequency at less than the normal rate of decrease of the inductive reactance of a substantially pure inductance, whereby losses in said coupling system between said stages are counteracted and the effective amplification of said amplifier stage is increased.

7. The combination with an audion tube having an input circuit adapted to be tuned over a band of frequencies of an output circuit including a composite impedance having inductive and resistive branches of fixed magnitude, the relative values of said branches being such that within the frequency range through which said input circuit may be tuned the effective inductance of said impedance increases with decreasing frequency.

8. The invention as set forth in claim 7, wherein the natural period of said inductive branch is higher than the highest frequency in the tuning range of said input circuit.

9. An electrical relay comprising a space discharge device having a tuned input circuit and an output circuit including an inductance element and at least one non-inductive element the various fixed circuit elements being of such relative values that within the limited range through which said input circuit may be tuned the effective inductive reactance of said output circuit automatically varies with varying frequency in a decidedly non-linear manner.

10. An electrical relay comprising a space discharge device having a tuned input circuit and and output circuit, said output circuit comprising fixed impedance elements proportioned so that within the range through which said input circuit may be tuned the effective composite reactance value of said output circuit automatically varies in a predetermined decidely non-linear fashion with varying frequency and that said impedance elements form a circuit having a natural frequency above the highest frequency in the tuning range of said input circuit.

11. An electrical relay comprising a space discharge device having a tuned input circuit and an output circuit, said output circuit comprising fixed impedance elements of such relative values that within the range through which said input circuit may be tuned the effective inductive reactance of the output circuit increases automatically as the operating frequency decreases and that said impedance elements form a circuit having a natural frequency above the highest frequency in the tuning range of said input circuit.

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