May 3, 1938. K. STEIMEL 2,115,889

CIRCUIT ARRANGEMENT FOR COUPLING ELECTRON TUBES

Filed Aug. 17, 1933

Fig. 1

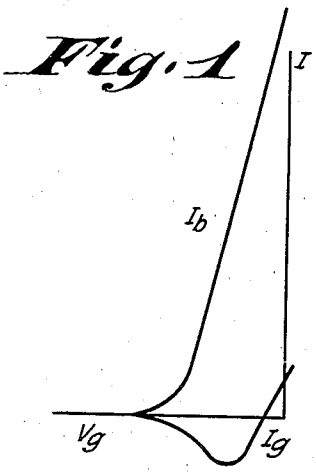


Fig. 2

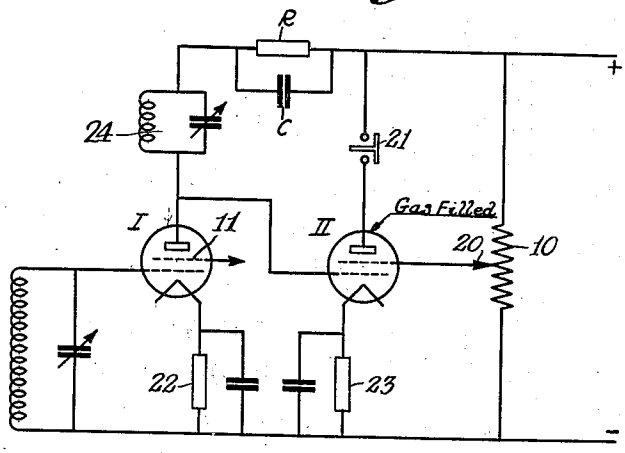


Fig. 7.

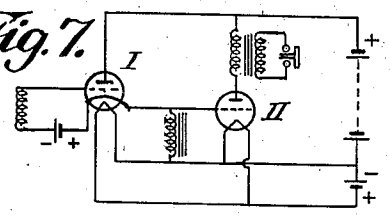


Fig. 3

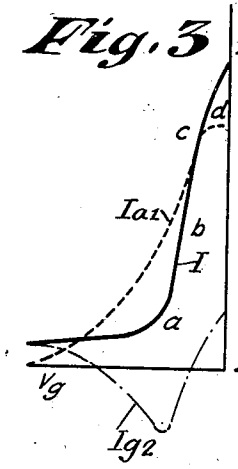


Fig. 4

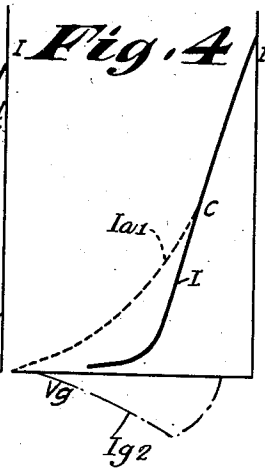


Fig. 5

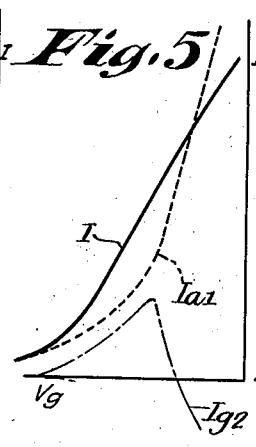
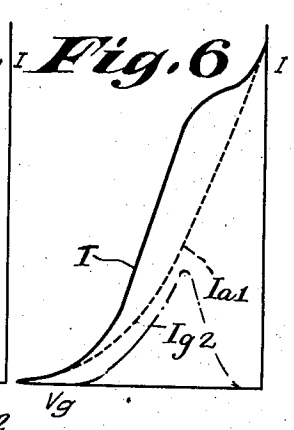


Fig. 6



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CIRCUIT ARRANGEMENT FOR COUPLING ELECTRON TUBES

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5 Claims. (Cl. 179—171)

This invention is concerned with a circuit organization in which two cascaded electron discharge tubes are in direct conductive coupling relation. Circuit arrangements are known in the prior art in which the plate and the cathode or filament of an amplifier tube are in direct coupling relationship with the grid of a following tube. When the second tube is worked inside the range of positive grid biasing voltage in order to raise the operating range and the efficiency of this stage, a grid current will be caused to flow which becomes superposed upon the plate current of the first tube. The grid current characteristic of the end or power tube is so composed or combined with the plate current characteristic of the input tube (preceding tube) that the resultant characteristic which represents the relation between the grid potential of the preceding tube and the total (or summation) current has as rectilinear as possible a form. However, it is found that the slope or steepness of the resultant characteristic is less than the slope of the characteristic of the preceding tube by itself. The net result is that the gain in energy obtained, since the operation of the power tube is pushed into the region of positive grid voltage, is purchased by a loss of slope of the characteristic of the preceding stage.

Now, the purpose and aim of the circuit scheme here disclosed is that, contradistinct to the schemes hereinbefore mentioned, there is on the one hand realized a gain in slope in reference to the rectilinear part of the resultant characteristic, while, on the other hand, the internal resistance of the combination circuit is raised, by transfer of grid current of a tube into the plate circuit of the preceding or input tube, it being thus possible to use high-ohm coupling impedances. If the resistance of the cathode-anode path of the first stage be denoted by R_1 and that of the cathode-grid path of the second stage by R_2, it will be seen that these two paths are in parallel hence their combination or joint resistance

$$R=\frac{R_1R_2}{R_1+R_2}$$

If now R_2 is chosen to be a negative resistance, the value and sign of R will depend on whether R_1 is greater than, equal to or less than R_2. If R_2 is negative and equal to R_1, then R will be infinitely great since the denominator of the fraction becomes zero. Applicant provides a tube for his second stage which is gas filled and means for controlling its screen grid voltage whereby the value of R_2 may be adjusted as desired. Another object is to realize an improvement of the characteristic bend with a view to insuring demodulation at high efficiency. By a circuit organization of the kind here disclosed it is possible at the same time to secure stable operation of tubes with a drooping grid current characteristic for which thus wider uses are obtained.

Tubes having a drooping grid-current characteristic, e. g., tubes with a gas atmosphere (filling) for the purpose of effects of space-charge are usually serviceable only in circuit organizations in which the grid-circuit resistance is lower numerically than the negative resistance of the grid-filament path measured in the drooping portion of the grid-current characteristic. Transformer coupling between the input tube and the grid circuit of the gaseous tube is not possible lest oscillations of a frequency equal to the natural period of the transformer be produced. The gain in slope realizable by tubes of this kind is rendered illusory by unduly low grid circuit resistance.

According to this invention, the grid electrode of a tube having a drooping characteristic is directly coupled with the anode of the input tube in such a fashion that the positive internal resistance of the input tube and the negative internal resistance of the grid-filament path of the next stage result in a combination resistance of extremely high value which makes the use of a high-ohm coupling resistance feasible, with the result that full utilization of the slope of the power tube is assured. By the term "drooping characteristic" is meant a curve or portion of a curve in which the slope is negative, or in other words wherein

$$\frac{dI}{dE}<0$$

I denoting the current and E the voltage of the curve in which I is some function of E. If the negative resistance of the grid-filament path is adjustable (for example, in the case of a gaseous tube by regulation of the screen-grid voltage), then it is possible to obtain infinitely high or even negative combination resistances having absolute values somewhat higher than the external anode circuit impedance of the first tube, thus resulting in maximum gain. If the coupling resistance consists of a tuned fly-wheel circuit, the same may thus be de-attenuated (regenerated) to a large degree this being accomplished, in standard regenerative circuit schemes, by variable coupling of the fly wheel inductance with the inductance coil of another circuit. It is known from practice that any change in coupling of such circuits causes an undesirable detuning of the resonance or fly wheel circuit. According to my invention this detuning of the resonant circuit is prevented by the expedient of utilizing a screen grid tube as the amplifier of the second stage and providing a means for controlling its screen voltage.

In addition to increased gain, it will be feasible to obtain in the combination characteristic further improvements, such as a sharper bend or knee for the purposes of rectification. If the plate current characteristic of the input tube and the grid current characteristic of the end or power stage, by suitable choice of the working voltage, are brought into such a mutual position that working at the knee in the grid current characteristic coincides with operation at the knee of the input tube, then conditions can be chosen so that the combination characteristic will present a more pronounced bend. Conversely, of course, the characteristic may be caused to assume such a relative position that the knees will offset with the consequence that the combination characteristics will become rectilinear inside a very wide range. The result is an increase of the range inside which undistorted amplification or operation is possible.

In the first place, the assumption will be made that the tube with drooping characteristic is of the type provided with a gaseous atmosphere with a view to diminishing space-charge effects. The properties of tubes of this kind which are important in connection with the present considerations, may be seen from Fig. 1 which shows the plate and the grid current as a function of the grid voltage. An explanation of this effect is that if the grid is made sufficiently negative no plate current will flow, hence no ions be formed to pass to the grid and the grid current will also be zero. As the control grid is made more positive (less negative) plate current will flow and form positive ions which flow to the negative grid, thus creating a negative grid current. As the grid potential is increased, this effect will increase to a point where the grid potential is not effective to attract more ions and the negative grid current reaches a maximum region. As the grid potential is increased still further (more positive) fewer and fewer ions will be attracted to it with accompanying decrease in the negative grid current. As it nears the cathode potential, negative electrons will be attracted to the grid with the formation of a positive grid current.

For a better understanding of the invention, reference is made to the accompanying drawing in which

Figs. 1 and 3 to 6 show characteristic curves of tube and circuit arrangements embodying the invention and,

Figs. 2 and 7 are schematic diagrams of circuit arrangements embodying the invention.

Fig. 2 shows a circuit scheme with which radio frequency amplification, rectification or detection, and power amplification may be accomplished. I denotes a standard input-stage tube which may either have a simple control grid or else which has in addition a screen grid as shown in the drawing. Tube II has a gas filling and it has therefore a drooping grid current characteristic as shown by the lower curve in Fig. 1. In the circuit shown the plate of tube I is connected to a positive potential source through a resonant flywheel circuit **24** in series with a resistor R, the latter being shunted by a condenser C. The inner or control grids are maintained at suitable negative potentials by the self bias resistors **22**, **23**. The screen grid **11** of tube I may have the usual positive voltage supplied by any suitable voltage source (not shown). A loudspeaker or other translating device **21** may be connected in the plate circuit of output tube II. The voltage of the outer or screen grid of this tube is controlled by the manual volume control **20** which is adjustable along resistor **10**. The negative resistance in the inner or control grid circuit of tube II is easily controlled by adjustment of contact **20**. By reason of the conductive connection of this grid to the plate of tube I, this negative resistance is in parallel with the positive plate resistance of tube I. Whenever a negative resistance is in parallel with a positive resistance and the two are of very nearly the same magnitude, their joint or combination resistance will be very much higher than either resistance alone and will be positive or negative according to which is larger. This high combination resistance in applicant's device is made effective since the internal impedance of tube I may be made very high by utilizing a screen grid tube therefor and also by supplying its screen grid with the suitable positive potential to effect this result.

Fig. 3 shows in full line a combination current characteristic referred to the control grid voltage of the input tube in contrast to the normal characteristic of the input tube shown in dash line. In Figs. 3 to 6 the plate current characteristic of tube I alone is shown by the dash lines (I_{a1}), the inner grid current characteristic of tube II by the dot and dash lines (I_{g2}) the resultant or combined characteristic by the full lines (I). It will be noted from Fig. 3 that the addition of the grid current of the power tube occasions both a sharpening of the lower bend *a* as well as an increase in steepness of the linear portion *b*. The bend at the top of the graph, at point *c*, may be rendered more acute by choosing the input tube of the screen-grid type, and by making the screen-grid voltage roughly of the same value as the plate voltage. By virtue of current transfer between these two electrodes, a sharp bend is produced which is designated by *d*. In order that the transfer of grid current from tube II to the plate circuit of tube I may be made faithful from both the frequency and phase viewpoint, the external impedence of the plate circuit of tube I must consist of a tuned resonance circuit **24** which acts like an ohmic resistance. Demodulation is effected by rectification in the combination circuit, the latter, for this purpose, containing a resistance R shunted by a condenser C. For this purpose either the upper or the lower knee of the combination characteristic could be used. In the latter case, there is obtained this advantage that the end or power tube is operated from the bottom end of the characteristic in an upward direction so that the direct current power consumption is minimized. The circuit shown in Fig. 2 effects radio frequency amplification detection and audio frequency amplification. The first tube and its parallel path including the grid-cathode path of the second tube serve to effect radio frequency amplification, the resonant circuit **24** representing the output impedance load. Rectification takes place by reason of resistor R and condenser C which it will be noted are in the grid circuit of the second tube. Audio frequency amplification is carried out in the anode-cathode path of the second or power tube.

Detection could also be effected in the plate circuit of the power tube rather than in the combination circuit; this would mean less delicate adjustment and consequent simplification of operation of the apparatus. The outside circuit arrangement could be made similar to Fig. 2, resistance R and capacity C, however, serving solely for voltage reduction and decoupling. The

plate circuit detection may be effected by giving the control grid of the second tube a suitable negative bias potential, as by inserting a biasing battery in the lead to its grid, in the known manner. The combination characteristic should be as straight as feasible, this being obtained by that, as shown in Fig. 4, the negative grid current is transferred at a point where the steepness of the input tube is already decreasing. Point *c* which characterizes a bend in Fig. 3 in the characteristic curve illustrated in Fig. 4 is a suitable operating point for linear radio frequency amplification. Regulation of the negative resistance of the grid-filament path, and optionally de-attenuation of the plate circuit is accomplished preferably by the screen-grid potential of the gaseous tube inasmuch as the value of the negative resistance depends largely upon its screen-grid voltage.

Also in circuit schemes nowadays customary in which the grid of the power tube is in resistance-coupling relationship with the filament of the input tube, and in which the coupling impedance or resistance is interposed between the filament and the negative pole of the plate potential source, by the use of tubes having a drooping grid current characteristic, a particularly favorable combination insuring a large working range is obtained as shown in Fig. 5. Such a circuit arrangement is shown in Fig. 7.

A drooping grid-current characteristic is insurable also by the use of secondary emission of the grid in question. Also in this instance, it is fundamentally feasible to employ a circuit organization as shown in Fig. 2. The operating potentials are so chosen that the control grid of the power tube operates inside the range of secondary emission. The combination characteristic is shown in Fig. 6. To adjust the value of the negative resistance, a suppressor grid interposed between the control grid and the plate of the power tube could be employed, the controllance conditions then being so chosen that the said suppressor grid will but slightly affect the primary electron current, while a powerful control action is exerted upon the secondary electrons. By choosing a suitable positive suppressor grid potential, secondary emission of the control grid can be specially favored.

Another method of insuring a drooping grid-current characteristic resides in the utilization of the current distribution between different positively biased electrodes of a tube. For this purpose, it is necessary to use a source of electrons having saturation properties whose emission current is practically not influenced by variations of the voltages of the other electrodes. This property is possessed by pure metallic filaments such as tungsten wires; but it is obtainable also by surrounding a heated cathode by one or preferably two space-charge grids, of which the outer one would have to be regarded as the electron source for the controlled discharge process. If the end or power-stage tube of Fig. 2 is of the twin-grid type and has a cathode with saturation properties as presupposed, then the first grid has a positive biasing potential, while the second one would be worked on a negative biasing voltage and act as a distributing grid. From a definite point the characteristic for the current flowing to the first grid would present a drooping characteristic, seeing that as a result of stronger flow of current to the plate, the current share of this grid would become smaller and smaller. The combination characteristic will then have a shape as shown in Fig. 6. The value of the negative resistance could be regulated by control of the potential of the said distributor grid.

Having described my invention, what I claim as novel and desire to secure by Letters Patent is:

1. A vacuum tube arrangement comprising the combination of an amplifying tube having a cathode, a grid, and a plate, a tunable input circuit connecting said cathode and grid, a tunable output circuit connected to said plate and means to cause regeneration of said tunable output circuit comprising a second tube having a gas filled envelope, a cathode, a control grid and a plate positioned in said envelope, a lead conductively connecting said control grid to the plate of said amplifying tube and a direct current connection between the cathodes of said tubes.

2. The combination defined in claim 1 in which means are provided for controlling the amount of regeneration of said tunable output circuit said means comprising a screen grid positioned between the control grid and plate of said second tube and means for varying the voltage applied to said screen grid.

3. An amplifying arrangement comprising a vacuum tube having a cathode, a signal control grid and a plate, an input circuit connecting said control grid and cathode, a circuit including a parallel resonant portion for applying a positive potential to said plate, and means for increasing the slope of the plate current-grid voltage characteristic of said tube comprising a second tube having a gas filled envelope, a cathode, a plate and a grid positioned between said cathode and plate, and a direct connection between said grid and the plate of said first named tube, the average potential of said plate and its connected grid being such that the portion of said envelope between its cathode and grid constitutes a negative resistance.

4. An amplifying arrangement comprising in combination a vacuum tube having a cathode, a control grid and a plate, a parallel resonant circuit and a resistor connected in series to said plate, a source of positive potential to one end of said resistor, a condenser shunted across said resistor, an input circuit connected between said cathode and control grid and including means for impressing a negative bias potential on said control grid whereby the grid voltage-plate current characteristic ascends with a more positive potential of said control grid and a second tube having a gaseous filling surrounding a cathode, a plate and a control grid located between said cathode and plate, means conductive to direct current connecting the said control grid to the plate of said first named tube and means for impressing such a voltage on the control grid of said second tube that the grid current characteristic thereof descends with increase of grid potential.

5. The combination defined in claim 4 in which the knees of the grid voltage-plate current characteristic of the first named tube and of the grid current characteristic of said second tube occur at the same grid voltage of said first tube.

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