Oct. 27, 1942. H. NYQUIST 2,300,133

BROAD BAND AMPLIFIER

Filed Sept. 20, 1940

FIG. 1

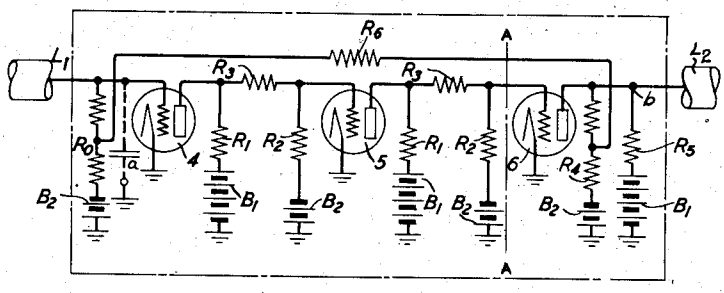


FIG. 2

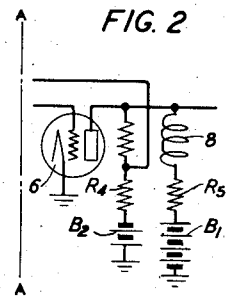


FIG. 3

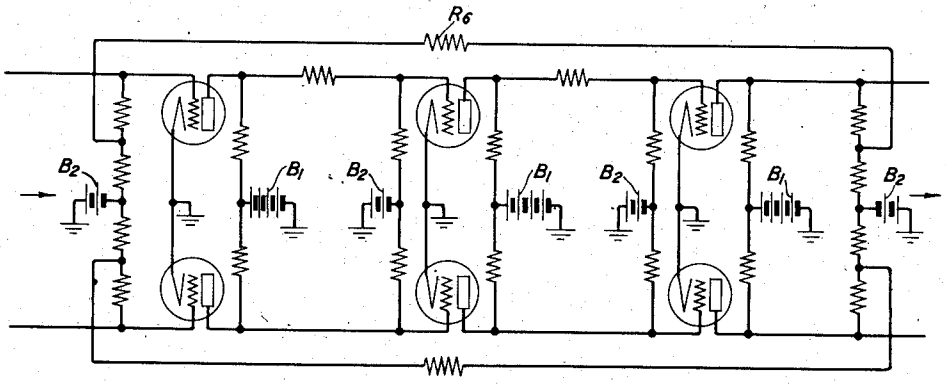


FIG. 4

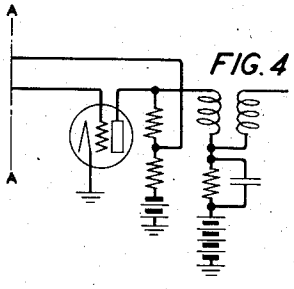


FIG. 5

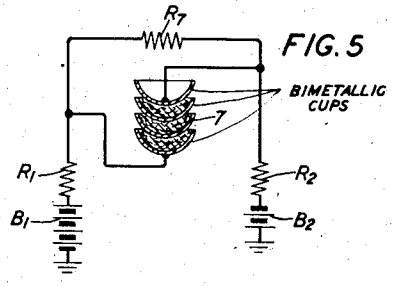
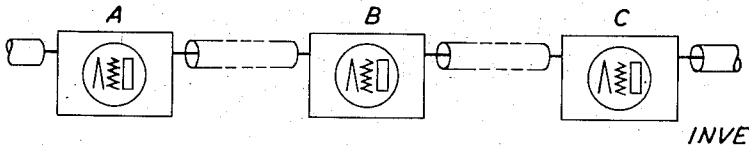


FIG. 6



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2,300,133

BROAD BAND AMPLIFIER

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Application September 20, 1940, Serial No. 357,517

3 Claims. (Cl. 178—44)

This invention relates to multistage broad band amplifiers and its object is that of designing an amplifier capable of operating over such a broad band as is commonly used in television. More specifically its object is to design an amplifier capable of operating effectively for direct current effects and for all frequencies from zero to several megacycles. A further object is to devise such an amplifier with negative feedback to provide the advantages ordinarily associated therewith. Still a further object is to devise such an amplifier in which the various stages may be supplied from common batteries or in which a plurality of such multistage amplifiers may be supplied from common batteries.

In connection with the amplification of television signals difficult problems arise because of the wide band of frequencies transmitted, giving a ratio of the order of 100,000 between the highest and the lowest frequencies. The provision of a band width of this ratio leads to difficulties from the standpoint of transfer design and from the standpoint of delay distortion, particularly when feedback is desired. I find that many of these problems disappear or are greatly diminished with a suitable design of amplifier going all the way to direct current, the amplifier being provided with feedback connections.

The invention will be better understood by reference to the following specification and accompanying drawing, in which

Fig. 1 shows a circuit diagram for an amplifier carrying out my invention;

Figs. 2 to 5 relate to modifications of the circuit of Fig. 1; and

Fig. 6 shows a system with a plurality of such amplifiers as are shown in Fig. 1.

Referring more particularly to Fig. 1 there is shown a feedback amplifier inserted between two lines L_1 and L_2, each with ground return. It will be observed that exclusive of heating batteries the amplifier employs a total of two batteries which are grounded. The amplifier itself is shown as a three-stage amplifier comprising the tubes 4, 5 and 6. The two interstage couplings comprise a resistance R_1 in series with the plate battery supply B_1, a grid resistance R_2 in series with the battery B_2 and a resistance R_3 connected to the resistance R_1, R_2 and from the plate of the tube to the grid of the succeeding tube. The input of the first tube comprises the resistance R_0 connected to ground through B_2. The output of the last tube comprises the resistance R_4 also connected to ground through B_2 and a resistance R_5 which may or may not be the same as R_1. A feedback connection extends from an intermediate point on R_4 to an intermediate point on R_0, this connection including a series resistance R_6. While for convenience there are shown several batteries B_1 and B_2 it is understood that there is but one battery B_1 common to all stages of the amplifier and that there is but one battery B_2 common to the grid circuit of the various stages.

Let it be assumed that the positive battery supplying current to the plate is 200 volts. The proper plate and grid potentials for the particular tubes used and for the desired points of operation are obtained by adjusting the various resistances shown. The points where the feedback resistance R_6 is connected are preferably so chosen that there is no current flowing through the feedback unless current is received from the line. This, however, is not an important requirement. Such a circuit as thus described will normally function as an amplifier which is independent of the frequency of the impressed signal. In some cases there may be a tendency for the circuit to sing at high frequencies due to the interelectrode and other capacitances present in the circuit. Such tendency towards singing can be prevented by a condenser connected as shown at *a*.

A readily observed advantage of the circuit as described is its simplicity, the amplifier consisting of nothing but tubes and resistance elements. There will obviously be a constant drain of battery power through the resistance networks, involving both an increase in the voltage and the amperage of the battery over that used in conventional amplifiers. On the other hand it is possible to select the tubes and resistances so that the waste power is not a serious factor economically. There will be some loss of output power in the bridged resistance but this may be remedied in a large degree by inserting an inductance 8 at the point *b* of Fig. 1 as shown in Fig. 2. This will cause high frequencies to be transmitted somewhat better than low, which would usually be an advantage.

Instead of using the batteries B_1 and B_2 as shown, one may use a generator or a rectifier with filters. While the impedance of a battery is negligible at all frequencies, the impedance of these other devices would be finite and would be a function of frequency, thus giving rise to a variation of gain with frequency. To overcome this and incidentally to reduce the effect of noise in the power supply and the effect of interstage coupling through the power supply, a

balanced push-pull amplifier may be used as shown in Fig. 3.

With a circuit such as shown in Fig. 1 it is likely that the impedance fit between the amplifier and the line may be poor. As far as direct current transmission is concerned such conditions may be improved only by the choice of low impedance amplifiers and by the choice of relatively high impedance lines, but this will frequently not be necessary. As far as the alternating current components are concerned the situation may be improved by the use of networks including transformers. One arrangement for this is shown in Fig. 4. The transformer here is outside the feedback circuit. It results, however, in transmission differentials as between alternating current and direct current, being in effect an equalizer.

It will be observed that there is a loss in the signal wave both because the output impedance of a tube circuit is lowered by the impedance in series with the positive battery and because the series resistance of the coupling between the stages causes a drop in the signal voltage available at the grid of the next tube. The former of these effects is not serious in wide band amplifiers because in the usual broad band amplifier it is necessary to lower this impedance artificially to get maximum band width. The second effect can be minimized by suitable design of the circuit constants. Moreover, the series impedance has value in broad band transmission because it tends to separate the interelectrode capacities in one tube from those in the other.

In the usual electrostatically controlled tubes the controlled and the controlling circuit have a point in common, namely the cathode. Moreover, the plate and grid differ in potential in the tubes commonly used. If in the usual circuit the plate of one tube is connected directly to the grid of the succeeding tube, it is required that the successive cathodes should differ in potential by an amount about equal to the normal potential difference between the plate and the grid. This, from the point of view of my invention, is undesirable because it does not permit the successive stages to use common batteries which is an important feature of my invention, nor does it permit the use of charging devices which are grounded or which have a high admittance to ground. If it is assumed that the successive tubes should have filaments which are at the same or nearly the same potential it would be necessary that some element be inserted between the plate of one tube and the grid of the next which insures that there should be a potential difference between them. In the arrangement described in Figs. 1 and 3 the resistance element R_3 carrying direct current has been shown and makes it possible to obtain the necessary potential difference between the grid of one tube and its cathode. This has the advantage from the standpoint of wide band transmission that a resistance element can be constructed whose admittance to ground is exceedingly small. It might be argued that the coupling resistances R_3 should be replaced by condensers. This, however, is ruled out in direct current amplifiers because it does not pass direct current. Moreover, it is objectionable in feedback amplifiers on account of the phase shift present at low frequencies. In addition the admittance to ground tends to be greater in a condenser than in a resistance.

An arrangement which has been used frequently in direct current amplifiers is to put the B battery in series with the plate of the one tube and the grid of the next and to ground a suitable point in the battery. This, however, excludes the possibility of using common battery and of using charging apparatus with high admittance to ground. Moreover, the admittance to ground of the battery is itself high.

An arrangement by which the losses due to resistances R_3 may be obviated is shown in Fig. 5. In this figure the battery supplying the power is as shown in Fig. 1 but the series interstage resistances are replaced by a string of counter-electromotive cells 7. These cells would be made of such materials and of such number that a small trickle charging current from the batteries is necessary to maintain them and the voltage which is developed will be highly constant and characteristic of the particular type of cells chosen. Under certain conditions it would also be desirable to shunt the cells by a high resistance R_7 giving an opportunity for these cells to discharge when necessary. Such a group of cells will be of low impedance and at the same time will offer a sufficient counter-electromotive force to reduce the power flow from the main batteries to a negligible amount and the cells themselves would require little or no maintenance. It is important that the string of cells shall have low electrostatic capacity to ground and this may be obtained by making the plates of the cell quite small. Each cell may be made of thin bimetallic cups about one-quarter inch in diameter and fitting inside one another with suitable separators and electrolyte. Obviously a wide range in choice of metals and electrolytes is available.

In Fig. 6 I have shown a communication system such as a coaxial line with a plurality of amplifiers of the type described in connection with Fig. 1. These amplifiers A, B and C are connected in tandem with such spacing as would be considered normal for the coaxial line. It will be observed that the coupling from the final plate in amplifier A to the initial grid in amplifier B is entirely similar to the interstage couplings within one of the amplifiers, the coaxial element being equivalent to the series resistance R_3. So far as direct current effects are concerned the couplings will be the same in form but may differ in magnitude in that the coaxial link will have the attenuation characteristic of alternating current signals and in that the resistance of the coaxial link may be different from that of the similar coupling resistances R_3. In general the system would be operated on such a basis that the attenuation in a coaxial link will be equal to the gain in one of the amplifiers, this holding for the whole frequency range of interest. It will be observed that there is a conductive path for direct current over the whole length of the system.

What is claimed is:

1. A multistage vacuum tube amplifier, and a conductive feedback path from the output to the input of said amplifier forming with said amplifier a negative feedback loop whose voltage transfer factor for a wide frequency range extending to zero frequency is substantially uniform and of greater order of magnitude than unity, each of the interstage coupling circuits of the amplifier comprising a resistance connected between a point of positive potential on a common source of space current for the tubes and the plate of one tube, a resistance connected between the grid of the following tube and a point

of negative potential on a source of grid biasing voltage for the latter tube, and a battery of counter-electromotive force cells connected between said plate and said grid and in series with said resistances and said sources, said battery comprising a series of thin bimetallic cups having a diameter as small as approximately one-quarter inch and fitting inside one another with suitable separators and electrolyte, the capacity of said battery to ground being at least as small as approximately 10 micro-microfarads.

2. A wave translating system comprising a multistage electric space discharge tube amplifier for amplifying substantially without distortion voltages of a wide range of frequencies including zero frequency, said amplifier having a conductive feedback path from the output of the amplifier to the input thereof forming therewith a negative feedback loop whose loop gain is substantially constant over said frequency range, each of the interstage coupling circuits of the amplifier comprising a resistance connected between a point of positive potential on a common source of space current for the tubes and the plate of one tube, a resistance connected between the grid of the following tube and a point of negative potential on a source of grid biasing voltage for the latter tube and conductive means for maintaining said grid at a lower unidirectional potential than said plate conductively connected between said plate and said grid and in series with said resistances and said space current and grid biasing sources and having its capacity to ground at least as small as approximately ten micro-microfarads, said system comprising also an incoming circuit conductively connected to the grid of the first stage of said amplifier for supplying thereto unidirectional and alternating voltages to be amplified thereby, and a utilization circuit conductively connected to the plate of the last stage of said amplifier for receiving therefrom and utilizing amplified unidirectional and alternating voltages.

3. A transmission system comprising a source of television signals of a band of frequencies from zero up to a frequency of the order of a million cycles per second, a plurality of spaced broad band amplifiers adapted to transmit and amplify said signals, one of said amplifiers having its input grid conductively connected to said source, each amplifier being a multistage amplifier having a conductive feedback path from its output to its input forming with the amplifier a negative feedback loop whose loop gain is substantially constant over said frequency band, each of the interstage coupling circuits of each amplifier comprising a resistance connected between a point of positive potential on a common source of space current for the tubes of the amplifier and the plate of one of said tubes, a resistance connected between the grid of the following tube and a point of negative potential on a source of grid biasing potential for the latter tube, and conductive means for maintaining the latter grid at a lower unidirectional potential than said plate conductively connected between said plate and the latter grid and in series with said resistances and said space current and grid biasing sources and having its capacity to ground at least as small as approximately ten micro-microfarads, said system comprising also a transmission line connecting said amplifiers in tandem, having one side of the transmission line conductively connected between the final plate of said one amplifier and the initial grid of the next amplifier whereby direct current as well as alternating current signals are transmitted over the system.

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