

Jan. 1, 1935.

A. NYMAN

1,986,597

SERIES COUPLED AMPLIFIER

Filed Feb. 25, 1931

5 Sheets-Sheet 1

Fig. 1

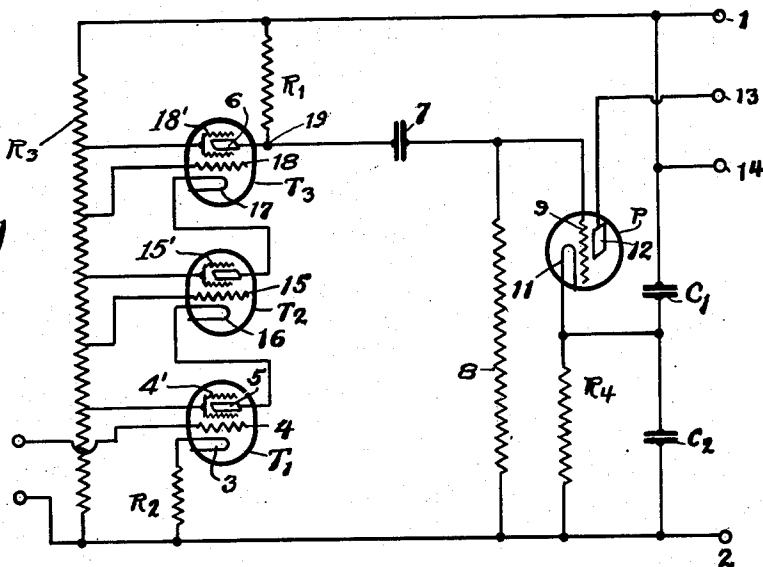
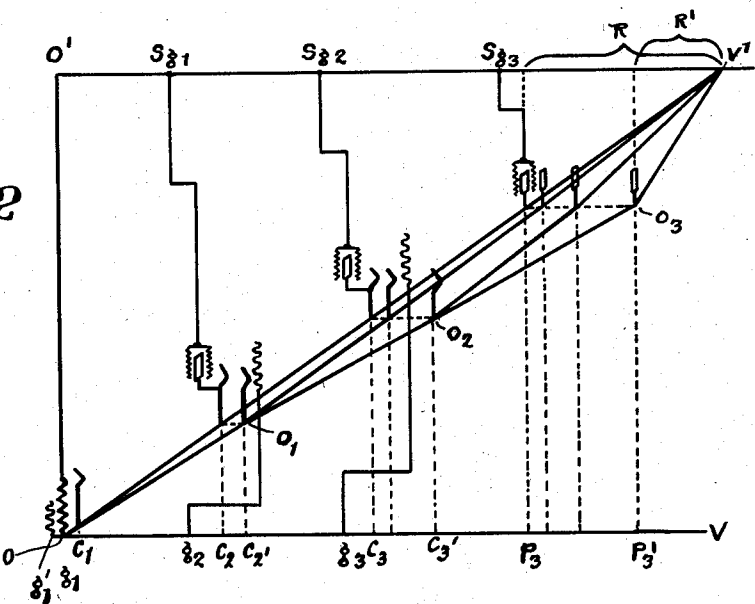


Fig. 2



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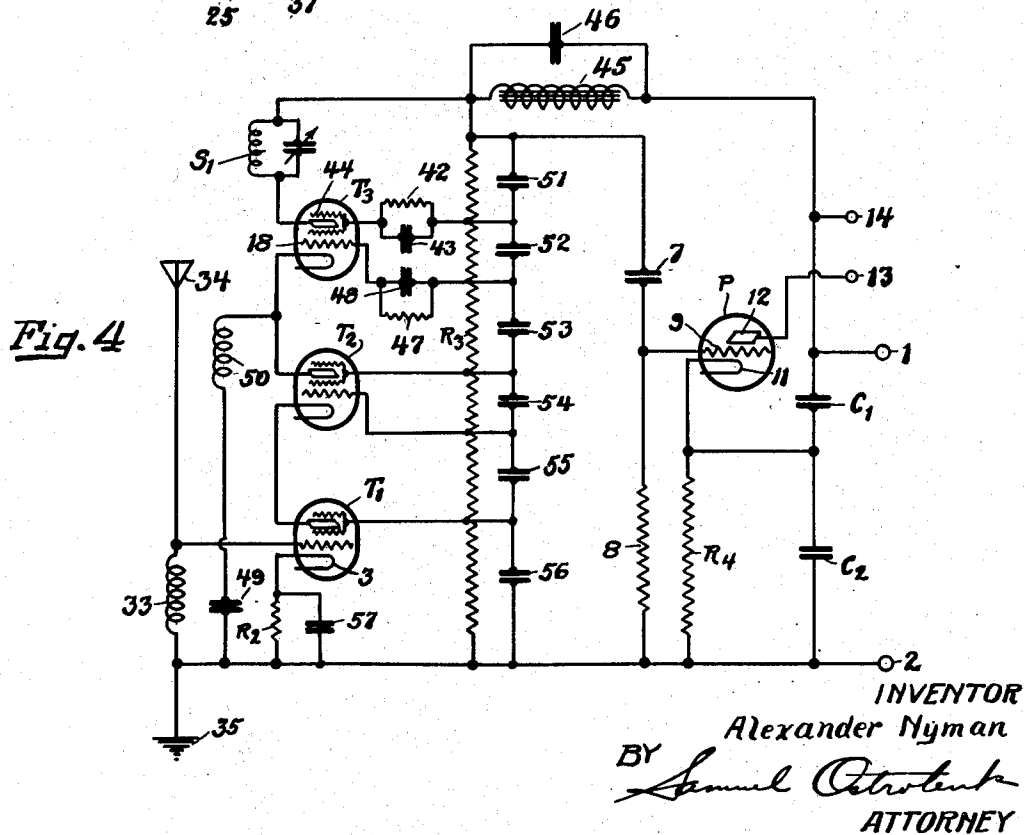
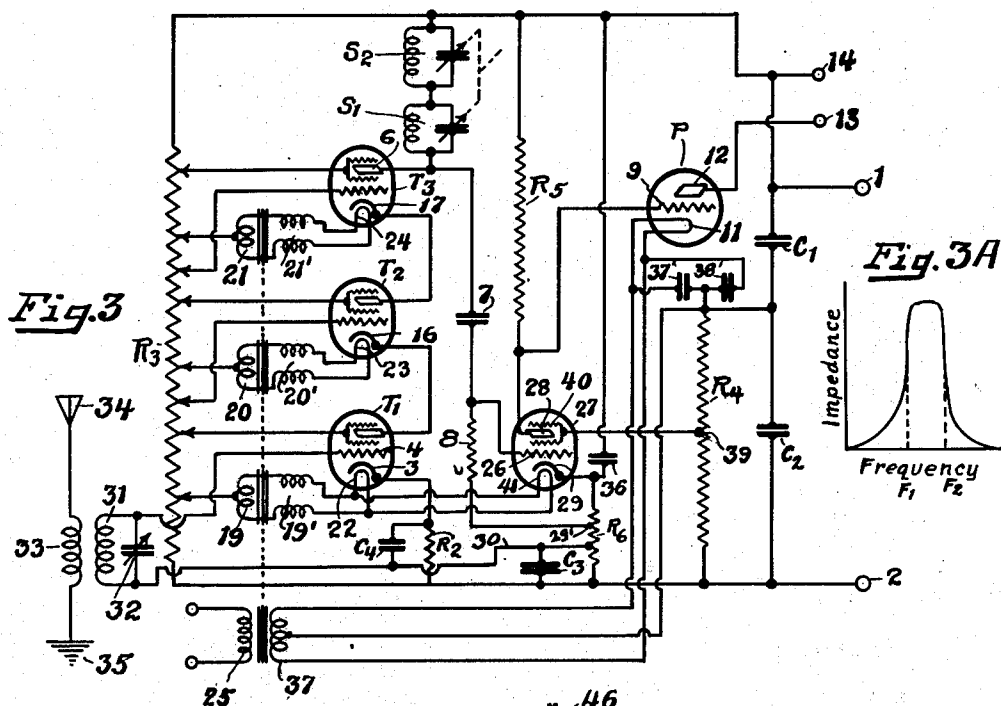
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5 Sheets-Sheet 2



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Fig. 5

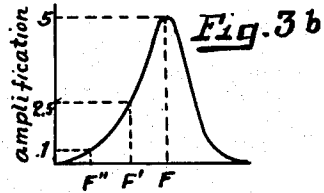
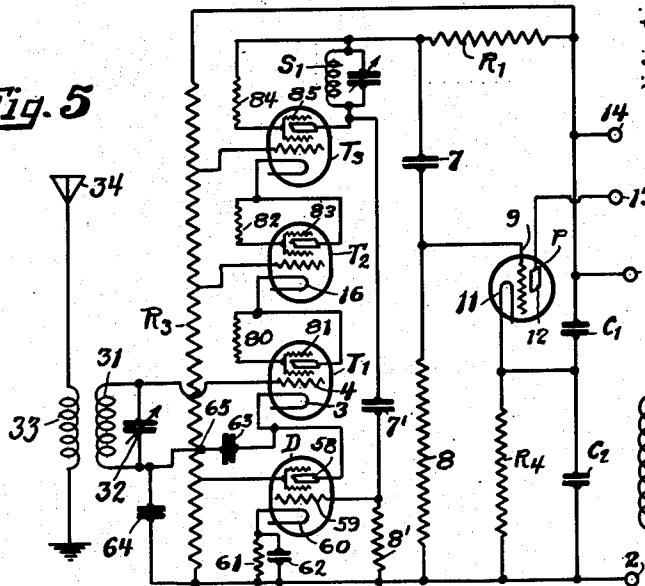


Fig. 7

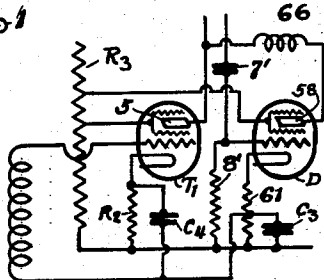
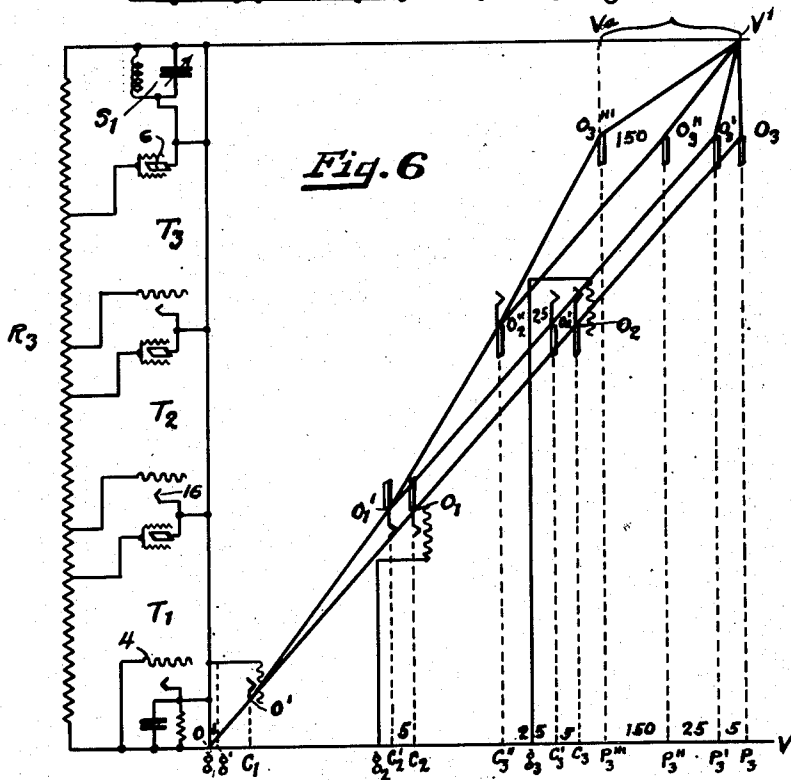


Fig. 6



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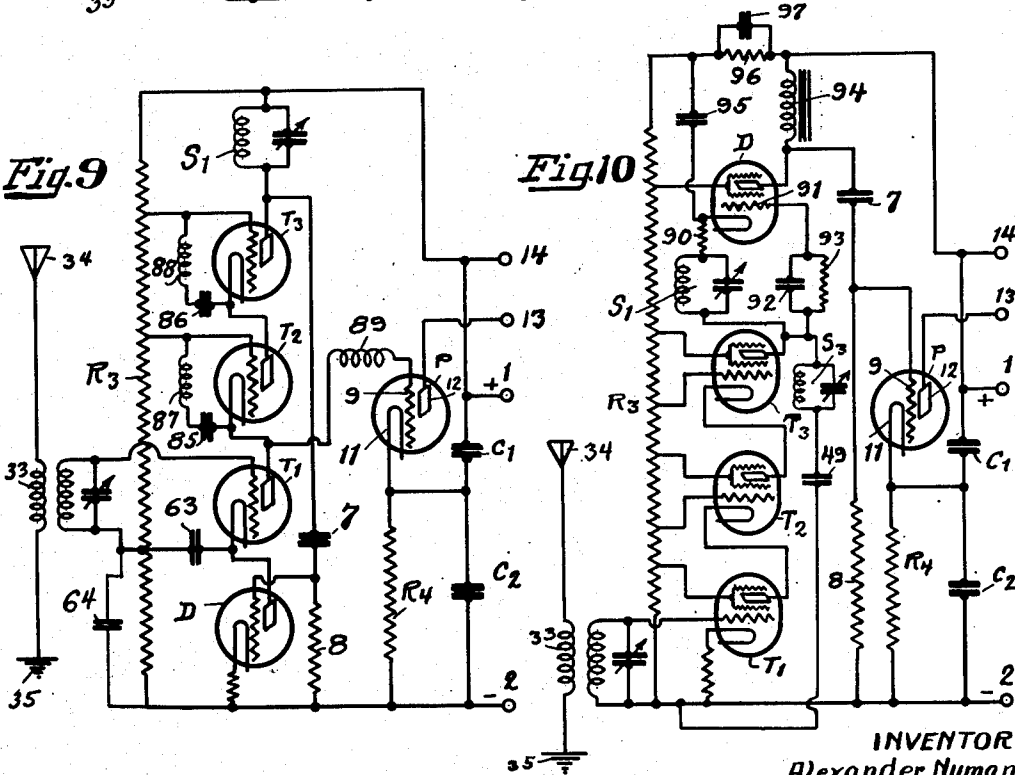
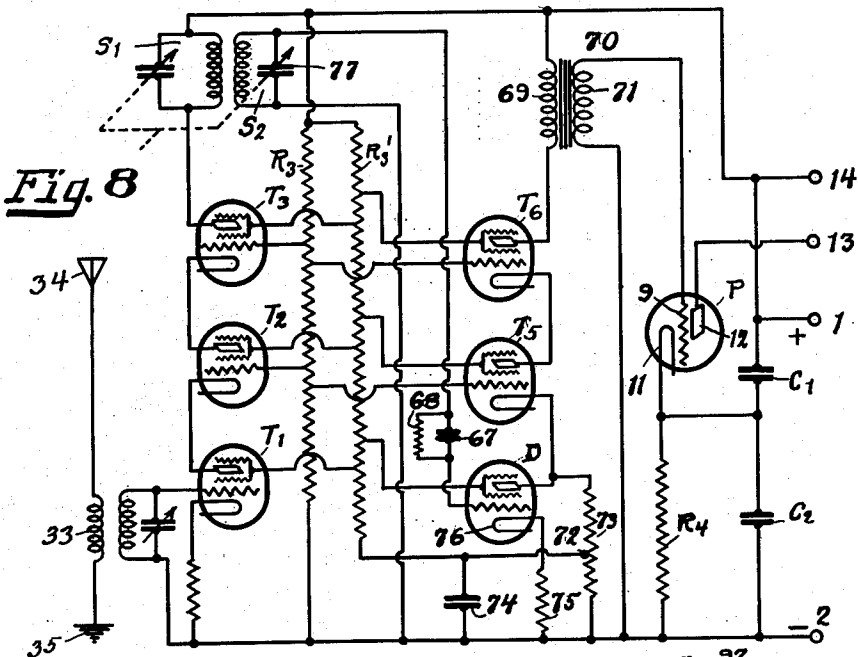
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SERIES COUPLED AMPLIFIER

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5 Sheets-Sheet 4



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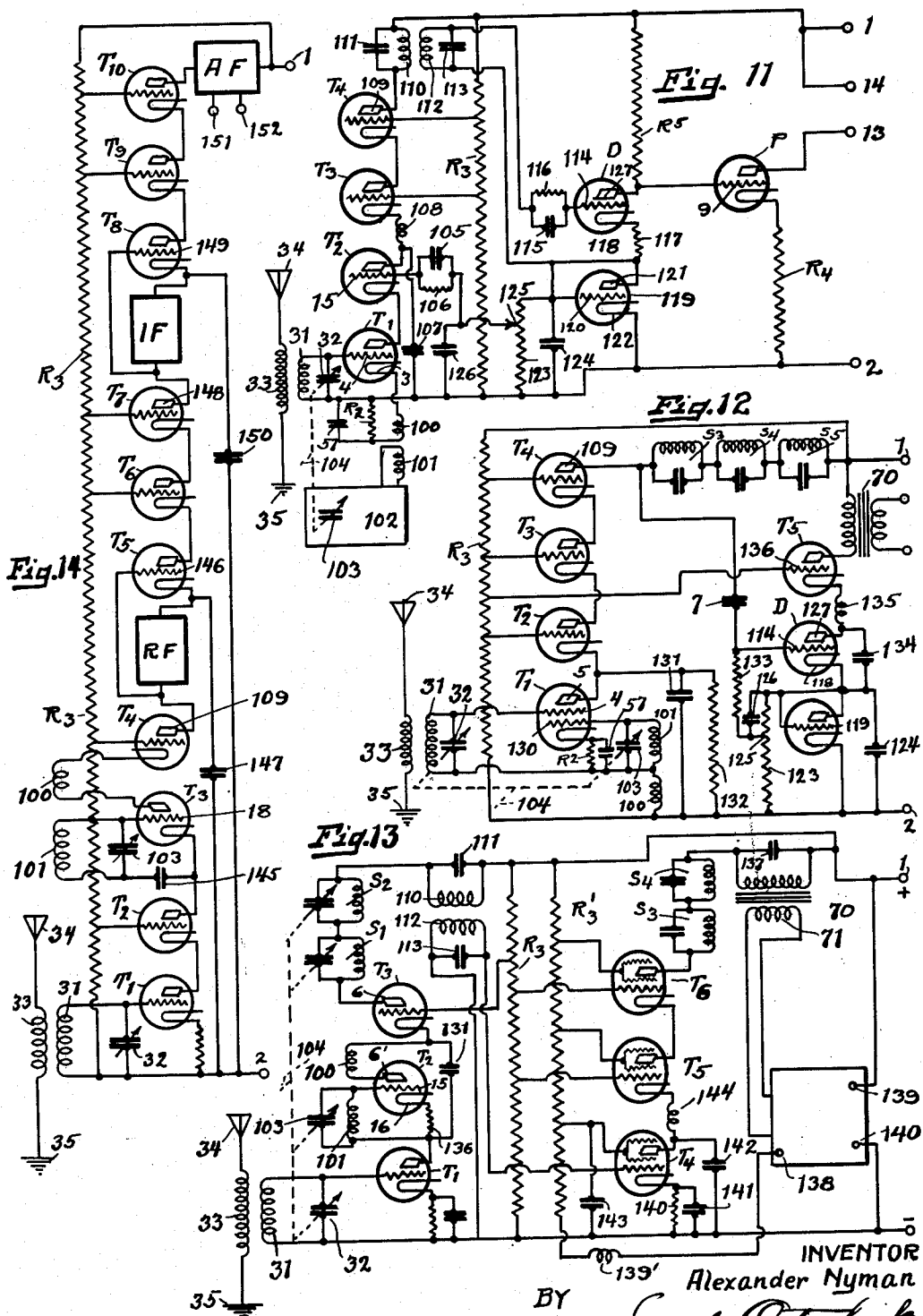
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SERIES COUPLED AMPLIFIER

Filed Feb. 25, 1931

5 Sheets-Sheet 5



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UNITED STATES PATENT OFFICE

1,986,597

SERIES COUPLED AMPLIFIER

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Application February 25, 1931, Serial No. 518,098

19 Claims. (Cl. 250—20)

My invention relates to a novel system for and method of amplification, and more particularly to a system which utilizes electric valves, such as thermionic tubes in series connection; that is, in such a manner that the anode of one tube is connected to the cathode of the next tube and the anode of said second tube to the cathode of the third tube, and so forth.

I have found that this novel system, when utilized with proper connections to control elements, is capable of achieving new and useful results, both with regard to degree of amplification and freedom from disturbing reactions and influences.

An object of my invention is, therefore, to provide means for using a system of series connected amplifiers for amplification of currents of all frequencies.

Another object is to provide means for using a series amplifier for amplifying currents of high frequency only.

A further object is to provide means for using a series amplifier for amplification of currents of selected frequency range.

Still a further object is to provide means for using a series amplifier of high frequency with a detector for demodulating and further amplification of modulated radio signals.

Still another object is to provide means for using the same series amplifier, first for amplification of radio frequencies, and, furthermore, after detection of the signals, for amplification of audio frequencies. A further object is to provide means in connection with a series amplifier of one frequency, for detecting and further amplifying the detected frequencies in a series amplifier and by-pass means for segregating the currents of different frequencies through their respective channels.

A further object of this invention is to utilize a series amplifier of one frequency in combination with detector of radio frequency and an amplifier of the currents at another frequency and reserving a portion of said series amplifier as a coupling element for further stages of amplification, at another frequency.

A further object of this invention is to utilize a series amplifier for super-heterodyne connections; that is, a connection where the original incoming signal is transformed into a different frequency, amplified at that different frequency and then demodulated to give the audio signals.

A further object of this invention is to utilize a series amplifier for super-heterodyne sets, including the necessary oscillators, as a part of the series amplifier.

A further object of this invention is to apply automatic volume control for different combinations of series amplifiers.

As will appear hereinafter in the technical analysis which follows, the series amplifier which constitutes the subject matter of this invention has several distinct properties, which I have discovered and which were not appreciated in the prior art, and which properties I make use of for simplifying the construction and utilization of radio sets and other amplifiers, both at radio frequency and at other frequency ranges.

One of these new properties is the fact that a common coupling element may be utilized for the whole series of amplifiers, instead of providing a separate coupling element for each stage of amplification, as has been the practice with the present type of amplifiers. Such a coupling element may be a resistor, a reactor, a transformer, or a tuned circuit, the latter being particularly useful for high frequency operation. It is quite evident, that the reduction in the number of coupling elements to a single unit materially simplifies the problem of tuning; particularly at the high frequencies, where adjustable, tuned coupling elements are utilized and where it was necessary in the prior practice to carefully adjust said elements to the same tuning in all stages and at all frequencies to which they may be tuned. Accordingly, with my invention, not only is the cost of additional coupling elements avoided, but, the careful adjustment and elaborate structural details for multiple control of several tuned coupling elements can be entirely discarded.

It is, therefore, a further important object of this invention to provide circuit means to reduce the number of coupling elements and, in particular, to utilize a single coupling element for the entire multistage series amplifier.

As stated above, an object of this invention is to utilize the same series amplifier, first at one frequency, then at another. I have found under such conditions that it will be useful to provide separate coupling elements for the separate frequencies, making them most effective for each particular range.

Therefore, a further object of my invention is to supply separate coupling elements for a series amplifier for each of the ranges of frequencies at which it is operated.

I have illustrated my invention with reference to a number of figures, some of which illustrate particular types of circuits and the others are diagrammatic to illustrate the operation of the series amplifier.

Figure 1 shows a resistance coupled series amplifier of the simplest type.

Figure 2 is a diagrammatic representation of the operating characteristics of this amplifier.

5 Figure 3 is a complete diagram of a radio receiving set, utilizing a series amplifier at radio frequency with a tuned coupling element and a resistance coupled audio frequency amplifier.

Figure 3—*a* illustrates the selective action of

10 a double filter used in Figure 3.

Figure 3—*b* shows the selective action of a single filter utilized in Figure 3.

Figure 4 is a diagram of a radio set, utilizing a series amplifier at radio frequency and demodulating the radio signals at one stage of this series amplifier.

Figure 5 shows an alternative arrangement of a radio set, using a series amplifier and a detector cooperating with this series amplifier in a reflex action.

Figure 6 is a diagrammatic representation of the theory of operation of a series amplifier with tuned circuit.

Figure 7 is another alternative connection similar to Figure 5, in which the detector is coupled to the series amplifier in a parallel relation.

Figure 8 shows a radio receiving set with two series amplifiers, one at radio frequency; another at audio frequency.

30 Figure 9 shows a radio receiving set with a series amplifier, wherein a portion of the series amplifier is used as a coupling element at audio frequency.

Figure 10 is another alternative connection of a radio set using a series amplifier for radio frequency and a detector cooperating with this amplifier.

Figure 11 shows a super-heterodyne radio receiving set using a series amplifier and a separate oscillator.

Figure 12 shows a super-heterodyne set with two series amplifiers; one at intermediate frequency, and another at audio frequency, and an oscillator incorporated in the first series amplifier.

Figure 13 shows another alternative super-heterodyne connection, wherein the oscillator is included in the radio frequency series amplifier chain and the intermediate frequency is supplied with a separate series amplifier.

Figure 14 illustrates diagrammatically the manner in which a series amplifier chain may be utilized successively at radio frequency, intermediate frequency and audio frequency.

55 Figure 1 shows a series amplifier with a resistance coupling element, which will be suitable for any frequencies. As seen from this figure, three thermionic tubes, T1, T2, and T3, are connected in series: that is, the anode of one tube T1 is connected to the cathode of the next tube T2, etc., and finally, the anode of tube T3 is connected through a coupling resistor R1 to the positive supply lead 1 of any suitable source of supply. The negative supply lead 2 is connected to the cathode 3 of tube T1 and may have a small resistor R2 of a suitable value to secure the grid bias voltage.

I have supplied a resistor R3 across the supply leads 1 and 2, which may be of relatively high resistance value with tap points to the different control elements or grids, these tap points to be adjusted, either during manufacture of a device or during the operation, to such points as will give the proper operating characteristics of the series amplifier, as will be discussed below.

The grid 4 and cathode 3 of tube T1 are used to apply the input potentials. The resistor R2 is included in the input circuit to secure a grid bias. The output of the series amplifier, may, for example, be connected to a point 19 which is the connection between the resistor R1 and plate 6 of tube T3 and, in this particular example, is shown to consist of a coupling condenser 7 and a grid leak 8 of a further power amplifier tube P, which, as is usual, may be of a different characteristic, for instance higher operating plate voltage, than the amplifier tubes of the series amplifier. A resistor R4 connected to the cathode 11 of a tube P may serve to produce the necessary grid bias potential, which is applied via the grid leak 8.

The plate 12 of the power tube P may be connected to an output circuit through terminals 13 and 14, the return circuit being through terminal 14 to the positive lead 1. I have, furthermore, supplied by-pass condensers C1 and C2, condenser C1 serving to return the variations of plate current of tube P to the filament circuit and the condenser C2 for by-passing the grid bias resistor R4. The condensers C1 and C2 are, moreover, in series across the input leads 1 and 2 and, therefore, help to smooth out pulsations of the supply voltage. The tubes T1, T2, and T3, may be, as shown, of the type having a screen grid 4', 15' and 18', respectively, and, in that case, the screen grid connections are applied to such points of the resistor R3 as will render these tubes most effective amplifiers for the purpose as will be described hereinafter.

The cathodes of the tubes T1, T2, and T3, may be heated either directly by applying a current from a transformer or a battery, or preferably by means of the so-called indirect heating; that is, by a separate heater element, which latter may be energized through transformers from a supply of alternating current. The method of connecting such heater transformers will be described below.

Referring to Figure 2, I have illustrated diagrammatically the manner in which such an amplifier will work. I have laid out along the abscissae the voltages which may be applied to the different elements of tubes T1, T2, and T3, and the coupling resistor R3, as illustrated along the line OV, the ordinate of this diagram being merely proportional to equal resistance units, so that the resultant distribution of voltage along the elements can be represented by a straight line, such as OV'. It is evident, therefore, that the distance C1—C2 represents the drop of potential through the tube T1, C2—C3, the drop of potential through the tube T2, etc., when no signals are received. On the other hand, the distance g1—C1 represents the grid bias of tube T1, g2—C2, grid bias of tube T2, etc. Similarly representing the voltages on the upper line O'V' to be exactly the same as on the lower line OV, the points Sg1, Sg2, and Sg3, represent the potentials of the screen grids of the tubes and R the drop through the resistor R1.

Considering now that a potential has been applied to the grid 4 to cause its potential to shift from g1 to g1', the effect of this would be to make the resistance of tube T1 higher, which is the property of amplifier tubes, and, therefore, change the voltage drop of this tube from C1—C2 to C1—C2', the voltage drop on the other tubes readjusting itself in accordance with the line O1V', since the resistance of these other tubes has not changed. It is evident that the shift

from C_2 to C_2' with respect to change from g_1 to g_1' represents the degree of amplification of tube T1 and will be, in general, several times the shift in grid potential from g_1 to g_1' , but by virtue of connection of the grid 15 to a fixed resistor R3, its potential remains fixed and, therefore, a new difference of potential is introduced between the grid 15 of tube T2 and its corresponding cathode 16. This voltage is now g_2 , C_2' which is considerably larger than g_2 , c_2 and will result in a change of the impedance of the tube, in such a manner that the drop of potential through tube T2 will now be represented by C_2' , C_3' , and the remainder of the voltage will be distributed over the line O_2V' . There is a slight simplification of analysis here as, as a matter of fact, the change in the impedance of tube T2 will cause a slight reduction in current and, therefore, also change the voltage C_1 , C_2' , but it will be readily seen that this change is automatically self-adjusting.

The new potential C_3' of the filament 17 of tube T3 is, as can be readily seen, widely separated from the original potential of this filament C_3 and, since the grid 18 of this tube is connected to a fixed resistor R3 and its potential is therefore fixed, the effect is of introducing a high negative bias of g_3 — C_3' in the tube T3 and a consequent high amplification in this tube. Thus, the plate 6 of tube T3 has its potential changed from point P3 to point P3' and the remainder of the voltage will be distributed along line O_3V' across the resistor R1. The diagram here again is simplified, since, as a matter of fact, the current through tubes T1 and T2 will also change slightly, due to the change in impedance of T3, but the change will never be the same as the change of voltage across resistor R1, since no tube can be regarded as purely a resistance element, but is rather equivalent to a fixed potential in series with a resistor. Thus, it is seen that the original voltage drop R across resistance R1 is now changed to voltage drop R', which is the result of the amplification of the original change of potential from g_1 and g_1' of the input grid 4.

Considering further the effect of the screen grid connections to the fixed resistor R3, it will be seen that on tube T1, the shift of its plate potential from C_2 to C_2' gives a very slight change in the operating characteristic with regard to the screen grid potential, since the screen grid potential is fixed. However, on tube T2 not only the plate potential has shifted from C_3 to C_3' , but also the filament potential has shifted from C_2 to C_2' . Therefore, the screen grid is now at a lower potential relative to the filament, and its controlling effect tends to limit the current and increase the impedance of the tube even further. The action of the screen grid is, therefore, to enhance the effect of the control grid and create a larger amplification.

Similarly, in tube T3 the filament potential is shifted from C_3 to C_3' , while the plate potential has shifted from P3 to P3'. The screen grid potential, however, has remained fixed and, therefore, in the new position it is closer to the filaments and the impedance of the tube is raised to give a greater amplification effect than with the control grid alone. The choice of the proper screen grid potential for the best operation of the system is, of course, dependent on the particular use to which the amplifier is put. Thus, for radio frequency amplification the effect of distributed capacity of the tube must be taken into account, the plate current must have such a value that the direct current impedance of the

tube is low relative to the impedance of its distributed capacity. On the other hand, at audio frequency, where the capacity effect is small, the greatest degree of amplification may be more desirable and, for that purpose, the screen grid potential may be adjusted to give a relatively high direct current impedance of the tube.

Referring to Figure 3, this shows a series amplifier consisting of tubes T1, T2, and T3 connected in a manner similar to Figure 1, but the coupling element is represented by one or more tuned circuits, such as S1 and S2. Each tuned circuit comprises an inductance and a variable condenser, adjusted to give resonance conditions over the range of frequencies at which this amplifier is adapted to operate. The object of utilizing more than one tuned circuit is to secure the broadening of the wave band to which the amplifier is responsive, for any particular setting. As illustrated in Figure 3a, the two tuned circuits provide a maximum impedance over a range of frequencies from F1 to F2, while Figure 3b shows a similar condition for a single circuit, such as S1, in which case there is a pronounced resonance very close to one frequency, such as F, and a gradual dropping off to both sides of these frequencies. For practical operation, the adjustment of the two circuits gives the best results when the difference of frequencies, F2 minus F1 is equal to about 10 kilocycles, thus including all of the side bands caused by the modulation of a radio frequency with ordinary musical and speech frequencies.

Referring to Figure 6, I have illustrated diagrammatically the manner in which the circuits, such as Figure 3, operate in a series amplifier. In this diagram, the abscissa OV represents the voltages on different elements of the series chain, while the ordinate illustrates the location of the different elements with respect to constant resistance units such, for instance, as the potentiometer R3. A tuned circuit S—1 is supplied in series with the chain and it will appear that the voltage distribution over the chain may be represented by the line O—O3, while the voltage across the tuned circuit S—1, which is constant, is represented by O_3V' .

It is also seen that the voltage on tube T1 is C_1C_2 ; on tube T2, C_2C_3 ; and tube T3, C_3P_3 . I have illustrated further the potentials of the various grids at points g_1 , g_2 , and g_3 . Considering now an application of potential of the value g_1 — g_1' at radio frequency to the grid 4 of tube T1. When this potential is applied in the direction as shown, that is, towards the cathode C1 of the same tube, it will result in the lowering of the impedance of the tube. Since at radio frequency, the tuned circuit S—1 prevents any changes in the current value, the voltage distribution will now change to a line O—O'—O1'—O2'—O3'; that is, providing that the impedances of tubes T2 and T3 have not changed. The total voltage change on tube T1 is, therefore, impressed on the tuned circuit S1 and is represented by the shift from O3 to O3'.

However, since in tube T2 the cathode 16 has changed its potential from C_2 to C_2' , being therefore closer to the grid potential g_2 of the same tube by a voltage C_2 — C_2' , there will be a change of impedance in tube T2 sufficient to shift its plate potential from O_2' to O_2'' . This second change in the potential of the plate of tube T2 is evidently the change of its cathode potential C_2 — C_2' multiplied by the amplification constant of this tube. On the other hand, the shift of the cathode potential C_2 — C_2' is the

result of the amplification of tube T1 and is, therefore, the shift of its grid potential gg' multiplied by the constant of amplification. Calling, for instance, the change gg' unity, with amplification constant of 5, the shift $C2-C2'$ would be 5 units and the shift $O2'-O2''$, 25 units. Therefore, the total shift of the potential of plate of tube T2 and also of the cathode of tube T3, which is connected to it, is from $C3$ to $C3'$, 5 units, and from $C3'$ to $C3''$, 25 units; a total of 30 units.

At this stage of consideration, the voltage is distributed along the line

$$O-O'-O_1'-O_2''-O3''-V_1,$$

that is, the total shift of potential would be shifted on the tuned circuit S1 and represented by $O3-O3''$. However, the impedance of tube T3 also changes by virtue of the change of its cathode potential from $C3$ to $C3''$. This change is illustrated by the line $O2''-O3'''$.

In other words, bearing in mind the fact that the current through the system does not change as the change in potential is taking place at the resonant frequency of the tuned circuit, the potential across the tube T3 will shift from the line $O2''-O3''$ to the line $O2''-O3'''$. While the potential on the other tubes T2 and T1, which has already been taken into consideration, will not change, and the resultant change of all of the voltages will be impressed on the circuit S1 and is represented by the value $V1Va$, amounting to the change of potential of plate of tube T3 from $P3$ to $P3'''$.

On account of the amplification in the tube T3, the change from $O3''$ to $O3'''$ is the change in potential of the cathode of tube T3 from $C3$ to $C3''$, multiplied by its constant of amplification. Thus if we take the constant of amplification as 5 and with the figures for the change of cathode potential of tube T3 from $C3$ to $C3''$ equal to 30, the change of the plate of tube T3 from $O3''$ to $O3'''$ will be 150 units, and the total change of the plate potential of tube T3 will be

$$5+25+150=180.$$

In general, the amplification with this type of amplifier will be expressed by the formula:

$$V=V_g N(N+1)^{P-1}$$

in which V is the final voltage change: V_g is the change in the grid potential of the input side; N the constant of amplification; and P is the number of stages. As in the usual type of parallel amplifier, the corresponding formula would be:

$$V=V_g N^P$$

It will be seen that the amplification in this system is slightly higher for the same number of stages.

Considering the amplification at some frequency away from the resonance point as, for instance, frequency F' of Figure 3b, it would result with one stage of amplification in an amplification one-half of that at frequency F . In other words, if the original amplification value was 5, the amplification now would be $2\frac{1}{2}$. The condition of the series amplifier circuit will now be evidently equivalent to that illustrated in the diagram of Figure 2, where, by virtue of the presence of resistance of the coupling element, the amplification value is about $\frac{1}{2}$ of the amplification constant.

Thus, if the amplification constant with a single stage is $2\frac{1}{2}$, the amplification with 3 stages would be approximately $2\frac{1}{2} \times 2\frac{1}{2} \times 2\frac{1}{2} = 15.6$, as against

an amplification of 180, of Figure 6. However, with resistance coupling, any change in impedance of the individual tube, causes a slight variation in current and, at the same time, a change of potential on the other tubes.

As was explained in connection with Figure 2, no consideration is given in this analysis to changes in the voltage distribution of tubes T1 and T2, when the impedance of tube T3 had changed. As was mentioned heretofore, the change of current through tubes T1 and T2 will reduce the effect of the change of impedance of tube T3, as they are more or less equivalent to another resistance on the opposite side to the coupling resistor R1. Therefore, the total amplification will be somewhat reduced. Thus, in the case under consideration where the frequency F' is coming in, the amplification is likely to be lower than 15, thus enhancing the sharpness of tuning of this circuit. Of course, as soon as the incoming frequency reaches a value F'' in which the impedance of the tuned circuit S1 is insufficient to give any amplification, no signal is amplified at any one of the stages and the voltage of the plate 6 of tube T3 will have even smaller variations than the incoming signal. The circuit is, therefore, particularly effective in eliminating disturbing frequencies.

Figure 6 illustrates the operation with ordinary three-electrode tubes, preferably of the separate heater type. As the cathodes of the tubes must change their potential, they must be isolated from any fixed potentials or grounded circuits, such as the heating transformers. Of course, separate insulated batteries for each stage may be used, or transformers with insulated secondaries separate for the tubes at each stage, and preferably protected by choke coils similar to the choke coils shown in Figure 3 in the heater circuit, may be used.

It is also often desirable to use tubes with more than three electrodes, such as screen grid tubes, and a simple consideration of the diagram of Figure 6 will make it clear that, if the cathode potential of tube T3 is shifted from $C3$ to $C3''$ and the anode potential is shifted from $P3$ to $P3'''$, the screen grid which is connected by means of the resistor R3 to a fixed potential, will become more positive with respect to both anode and cathode, and hence, it will lower the impedance of the tube and result in a more pronounced amplification. In other words, the screen grid acts in the same direction as the control grid, for the purpose of amplification.

Although the consideration of Figure 6 was for operation at radio frequency with a tuned circuit S1 for coupling purposes, it is quite evident that identical consideration may be applied to audio frequency amplification, if the circuit S1 is replaced either by a choke coil of sufficient magnitude to prevent variations of current at the lowest audio frequency, or by a suitable transformer. Of course, a resistance can be used for coupling at audio frequency, but in that case the diagram of Figure 2 and the accompanying consideration is more strictly applicable.

It is also possible to utilize the same series amplifier for amplification both at radio frequency and at audio frequency, as illustrated in Figures 5, 7, and, furthermore, at three different ranges of frequencies, as illustrated in Figures 11, 12, and 14. The conditions which must be fulfilled are that the coupling elements, supplied for each range of frequency, are designed to offer high impedance for changes in current of that fre-

quency, and also, that if there are any changes at any one range of frequencies, then this change of current must be by-passed from the tubes operating on another range, as is illustrated, for instance, in Figures 4 and 10.

It is well known that with a type of tube illustrated in many of the drawings, known as the screen grid tube, or with other types of tubes known, as space charge tubes, having an extra control electrode, it is possible to vary the amplification constant. A reference to technical literature on this subject may be found, for instance, in the Proceedings of the Institute of Radio Engineers of February, 1929, where, on page 327, a diagram is given of the variation of the amplification constant and of the other constants of the tube, with the changes in the screen grid potential. Similarly, an article in the Proceedings of the Institute of Radio Engineers for May, 1929, on pages 830 to 833, discusses the operation of screen grid tubes and space charge grid tubes, as detectors, showing the various advantages of this type of tube for this purpose.

Thus, any particular amplifier connection can be laid out, with the full knowledge of the operating characteristics of the tubes for the purpose intended. Moreover, the screen grid connection or the space charge grid connection to the common potentiometer R3 may be utilized for the purpose of changing the amplification constant of the series amplifier. This arrangement has been carried out in Figure 8, but can evidently be applied also to other systems.

Where a screen grid tube or a space charge grid tube is used as a detector, as a part of the series amplifier as, for instance, in Figures 5, 7, and 8; such a detector tube may have volume control by the proper changes in potential of the screen grid or the space charge grid of detector tube. However, the more usual method of volume control is by changing the control grid potential of an amplifier or detector tube. This can also be applied to the series amplifier, as for instance, illustrated in Figures 3 and 7.

In parallel type amplifiers, a very common phenomenon which must be guarded against is known as regeneration and consequent oscillation. This phenomenon is due to a reactive or capacitive coupling between the different stages of the amplifier and is attributable to the fact that in most parallel connected amplifiers there is a reversal of the phases of the amplified currents or potential on successive stages. Thus, a capacitive coupling between two stages would introduce regenerative action with great facility. It will be observed, for instance, from the consideration of Figure 2 or Figure 6, that the changes of potential in successive stages of series amplifiers have the same phase; that is, lowering of cathode potential in tube T1 with respect to its grid; that is, from gC_1 to $g'C_1$, as illustrated in Figure 6, results in a lowering of the cathode potential of tube T2 and in a further lowering of the cathode potential of tube T3. Thus, even if there is capacitive coupling between tubes of successive stages, such coupling would, in general, produce a reduction of amplification or degeneration and would effectively stabilize the system from any oscillations. In other words, the series amplifier is inherently stable, while the parallel amplifier is inherently unstable.

While I have shown, in Figure 3 and the other figures, arrangements for automatic volume control which constitutes the preferred form of vol-

ume control as it becomes independent of the operator of the radio set, yet it is quite evident that in Figure 3 or in any of the following figures where the volume control is applied, that this may be of the ordinary manual type; that is, controlled by the operator and achieving the same type of reduction in amplified impulses as the automatic control.

Also, I have illustrated in all of the figures the usual type of thermionic valves consisting of a heated cathode, an anode, and one or more control grids. However, the circuits illustrated in these diagrams can be applied also to other types of electrical valves and especially to glow discharge valves which have operating properties somewhat similar to thermionic valves; that is, they have main electrodes carrying the discharge current and one or more control electrodes for determining the particular value of the discharge current. Among such discharge valves there are some where the controlled potential is applied between anode and the control electrode rather than between cathode and the control electrode, as in the thermionic tube. In that case, the connections, as illustrated in the different diagrams, would have to be modified in so far as the coupling element has its most effective position next to the electrode in which the original impulses appear in amplified form. Thus, with thermionic valves the coupling element is generally most effective when connected next to the anode of the last tube of the series amplifier. If, however, discharge valves are used in which the input is applied between anode and control electrode, then I would preferably connect the coupling element next to the cathode, and on the negative end of the series amplifier. Also, the input connections would be applied to the valve next to the positive end; that is, the same connections as illustrated may be used except that the potential applied to terminals 1 and 2 will be reversed.

The effect of introducing either one or more tuned circuits, such as S1 and S2 in series with the amplifier, is to multiply the effectiveness of the selective action of said tuned circuits by the amount of amplification of the series amplifiers. In other words, a single tuned circuit, such as S1 with 3 stages of series amplification, such as tubes T1, T2, and T3, becomes equivalent in its selective action to three stages of parallel connected amplifiers of the usual type with three independent tuned circuits, all adjusted to the same frequency.

Similarly, an arrangement as shown in Figure 3 with two tuned circuits S1 and S2, the tuning of which is slightly staggered to keep a frequency range of 10 kilocycles and connected in series with three stages of series amplifier, is equivalent to a parallel amplifier of three stages with six tuned circuits, two to each stage; each one adjusted exactly the same as the present combination of S1 and S2.

In the practical manufacture of amplifier circuits, it has been customary to adjust the tuning circuits of all stages to be controlled by a common means. For such a circuit it is necessary to secure a very uniform construction of the coils and condensers of the different tuning circuits, and moreover, to employ elaborate methods for adjusting accurately each tuned circuit to be exactly of the same frequency as the other circuits, for any particular setting of the variable condenser. In fact, this has been one of the most serious difficulties experienced in the assembly of

the amplifier circuits, and has caused no end of trouble, both in manufacture and in subsequent readjustment due to slight variations in the values of capacity or inductance.

5 All of these difficulties are entirely eliminated in the arrangement of series amplifier without any sacrifice in the amount of amplification to be secured or the selectivity of the resultant amplifier. It is necessary to supply only one
10 tuned circuit with no arrangements for multiple control, or if a double circuit, such as illustrated in Figure 3, is desired, only the two condensers of the two circuits S1 and S2 need to be adjusted to cover the necessary frequency range, as illustrated in Figure 3a, for all of the settings of these
15 condensers.

I have shown in Figure 3, the control and screen grids of the tubes T1, T2, and T3 connected to a resistor R3, similar to that of Figure 1, and I have
20 also shown diagrammatically the secondary windings 19, 20, and 21 for the tubes T1, T2, and T3 connected through choke coils 19', 20', and 21' to the heaters 22, 23, and 24 of the three tubes; these heaters being of the usual type in close proximity to the corresponding cathodes 3, 16, and 17.

25 The object of the choke coils 19', 20', 21' is to prevent any radio frequency currents that may have reached these leads through the capacity between the heaters and the cathodes, or through the electrical leakage therebetween, to be grounded by virtue of the capacity of the secondary
30 windings to the core of the transformer, and to the primary circuit 25. I have, moreover, supplied connection from the center points of the transformer windings 19, 20, and 21, to the resistor R3 by means of which a potential is applied to the
35 heaters normally below the potential of the cathode to minimize such leakage as may take place.

As shown, the plate 6 of the tube T3 is connected through a coupling condenser 7 to the grid 26 of an amplifier tube 27 and to a grid leak 8 of
40 tube 27. Tube 27 may be connected to further amplifiers in any desired manner, but I have shown in this figure a direct coupling from the plate 28 of this tube to the grid 9 of a power amplifier tube P and to resistor R5. Resistor R5
45 supplies positive potential from supply lead 1 to the amplifier tube 27, and at the same time, provides a resistance coupling to the grid 9 of tube P.

50 Connected between the cathode 29 of tube 27 and the negative lead 2, is a resistor R6 which serves, by virtue of its drop of potential, to give potential bias from the tap 29' to the grid 26 through the grid leak 8. A condenser C3 shunts a
55 portion of the resistor R6, and a connection 30 from this condenser extends to the input circuit and the grid 4 of tube T1. The condenser C3 is chosen of such a value, with respect to the part of the resistor R6 which it is shunting, that the
60 time constant of this combination is relatively long. Thus, if the signal coming through the system maintains an excessive value over a period of time, say of one second or more, the definite change, such as lowering of the electronic current
65 through tube 27, will cause a change of potential across the condenser C3, which is applied to the input circuit of series amplifier, and thereby changes the potential of the controlling grid 4 of tube T1. Since the lowering of the electronic
70 current through tube 27 will result in the lowering of potential on the condenser C3 and a consequent lowering of the control grid potential in the input tube T1, it is evident that the amplification of the tube T1 will be reduced and therefore, the
75 resultant signal to tube 27 will also be reduced.

I have shown the grid 4 of tube T1 connected through a circuit, which may or may not be tuned, and consisting, for instance, of an inductance 31 and variable condenser 32, to the negative lead 38 which, by virtue of the tapped section of resistor R6 and of resistor R2, similar to that of Figure 1, will give a necessary negative bias to the input tube T1. The coil 31 may be coupled to another coil 33 which is connected to antenna 34 and ground 35. There is also a by-pass condenser C4 for the input circuit lead 30 to the cathode 3 of tube T1.

8 Connected between the cathode 29 of tube 27 and the positive lead 1 is a condenser 36, the object of which is as follows: Direct current supply on the leads 1 and 2 will, in general, have a certain amount of pulsations of potential caused either by imperfections in filtration of rectifying current, or by some other causes. It will be seen that such pulsations of potential will be coupled through the condenser 7 and grid leak 8 to the grid 26 of the tube 27, and hence cause a certain amplification of these pulsations in tube 27, unless the cathode 29 can be made to have exactly the same pulsation potential with regard to the phase and amplitude as the grid 26. By choosing a proper value of condenser 36 with respect to resistor R6, such a value of pulsation potential can be easily procured and hence the amplification of pulsations prevented.

9 The power amplifier tube has a plate 12 connected through the output terminals 13 and 14 to the positive supply terminals 1, while the cathode 11 is supplied from a secondary 37 of the heater transformer and may utilize the same primary 25 as the heater secondaries 19, 20, and 21, as indicated by the dotted lines. The center point of transformer 37 is connected to the cathode resistor R4 and hence to the negative lead 2. Bypass condensers 37' and 38' may be supplied across the cathode with the center connection to the resistor R4. The resistor R4 may be also tapped at some point 39 for the potential of the screen grid 40 of tube 27, while the heater 41 of tube 27 can be readily supplied either from the secondary 19 of the heater transformer of tube T1 or else by a separate secondary or by a separate transformer.

10 I have shown a condenser C1 as a by-pass on the power tube P and the output circuit, and a condenser C2 as a by-pass of the resistor R4. The condenser C2 may be adjusted to such a value that the potential of the cathode 11 with regard to pulsation voltage is exactly the same in amplitude and phase as the pulsation potential applied to grid 9 of the same tube by virtue of resistor R5 and tube 27. By this means, the amplification of such pulsations in tube P are successfully prevented.

11 Referring to Figure 4, I have shown an alternative arrangement wherein the tube T3 can be utilized as a detector, by means of a grid leak 42 and a grid condenser 43 connected between the screen grid 44 of tube T3 and its point of connection to resistor R3. Since, with a radio frequency signal going through tube T3, there will be a certain amount of rectification on the screen grid 44, an arrangement of such a grid leak 42 and grid condenser 43 will obtain a demodulation of the signal and a consequent introduction of audio frequency changes of impedance of tube T3. These changes of impedance can be utilized by a provision of either resistor, choke coil, or transformer coupling, such, for instance, as the choke coil coupling illustrated in Figure 4 and con-
75

sisting of an iron core choke 45 with a by-pass condenser for radio frequency 46 and a coupling lead through condenser 7 to the grid 9 of a power amplifier tube P. The connection of the power amplifier tube P has been fully described in connection with Figure 1, and needs, therefore, no further discussion.

In addition to the rectification through the screen grid connection, I may also supply rectification through the control grid by providing a grid leak 47 and a grid condenser 48 between the control grid 18 of tube T3 and its point of connection to resistor R3. It is also possible to omit the resistor 42 and condenser 43 and utilize the condenser 48 and resistor 47 alone for demodulating purposes.

The tube T3 will now have variations of impedance at audio frequency. These variations of impedance will impress a voltage change on a series choke coil 45 and also on the amplifier tubes T1 and T2. The changes on the choke coil 45 are the useful changes applied to the grid 9 of a further amplification stage. Those, however, which may be impressed on the tubes T1 and T2 would cause a reduction in the audio frequency amplification, since they would be subtracted from the potential change across the tube T3 at its plate circuit connection.

In general, if the changes of current at audio frequency are successfully prevented by the presence of the choke coil 45, there would be no changes of potential across the tubes T1 and T2, but inasmuch as there is a possibility of this choke coil being not entirely effective in suppressing the changes in current, I have supplied a by-pass condenser 49 in series with radio frequency coil 50, by means of which the audio frequency changes are by-passed around the tubes T2 and T1, while the radio frequencies are prevented from being short-circuited through this by-pass.

I have also supplied a series of by-pass condensers 51, 52, 53, 54, 55, and 56 across the various taps to the different control grids and screen grids, so that if any current passes through these grids at radio frequency, this current would not cause any variation of the potential, being by-passed by the above by-pass condenser. I have also supplied a by-pass condenser 57 from the cathode 3 of tube T1 to the negative lead 2 and across the resistor R2, which serves for the biasing of the input circuit. I have shown in this diagram an antenna 34 with a ground connection 35 coupled directly to the input circuit by means of coil 33. Since the selectivity of circuit S—1 in series with the series amplifier is such as to segregate all of the disturbing frequencies, it may not always be necessary to supply a tuned circuit in series with the antenna and an arrangement, as shown, is satisfactory.

Referring to Figure 5, an alternative arrangement of detector is shown, wherein a separate detector tube D is utilized. It is connected in series with the tubes T1, T2, and T3 in such a manner that the plate 58 of tube D connects to the cathode 3 of tube T1. A coupling condenser 7' and grid leak 8' connect the grid 59 so that the tube D acts as a detector for radio frequency oscillations arriving by the condenser 7'. As the tube D is connected to tubes T1, T2, and T3 in the series amplifier system with respect to a coupling resistor R1, similar to that of Figure 1, this system will also amplify the changes of impedance at radio frequency, resulting from the demodulation of radio signals by the detector D.

In other words, the tubes T1, T2, and T3 are

used as a series amplifier at radio frequency backing up against tuned circuit S1, and also as a series audio frequency amplifier backed up against a coupling resistor R1. The voltage across the resistor R1 can be further utilized by a coupling condenser 7 connected to the grid 9 of the power tube P with a grid return lead through the resistor 8 to the negative lead 2. The remainder of the connection of the power tube may be the same as in Figure 1. As shown, the cathode 60 of the detector tube D is connected through a resistor 61 to the negative lead 2 and a by-pass condenser 62 supplied across the resistor 61. This resistor serves to provide the proper grid bias to detector D and the combination may also be utilized for automatic volume control.

I have also shown by-pass condensers 63 and 64 and a connection of the input circuit to a point 65 on the potentiometer R3, from which the proper grid bias for tube T1 is secured. The input circuit is shown to be similar to that of Figure 3, but any other modification may also be utilized, as the real tuning is accomplished by the circuit S1. The by-pass condenser 64, together with condenser 63, permits the variations of potential of radio frequency to by-pass the detector tube D and thus have the radio frequency amplification unaffected by the presence of the impedance of tube D. On the other hand, since the grid 4 of tube T1 has a permanent connection at point 65 to resistor R3, the tube T1 will act as an audio frequency amplifier for the variations of impedance at audio frequency in tube D in exactly the same manner as is illustrated in Figure 2.

Although I have shown a resistance coupling R1 for the audio frequency signals, it is evident that other types of coupling may also be used, such as a choke coil coupling, similar to Figure 4, or transformer coupling, similar to Figure 8.

I have shown in Figure 7 another modification by a partial drawing representing the tube T1 and the detector tube D in a different arrangement from that of Figure 5. The circuit is only partially shown, but the elements will be identified without difficulty. The tubes T1 and D are in this case connected in parallel; that is, the respective plates 58 and 5 of the tubes D and T1 are connected to the cathode 16 of tube T2. The tube D is prevented from being a shunt at radio frequency on the tube T1 by means of a choke coil 66 in its plate circuit, and the tube T1 is prevented from being a shunt at audio frequency by a proper adjustment of its grid bias by means of the grid bias resistor R2 and possible volume control derived from the resistor 61, in a manner similar to Figure 3; that is, in combination with a condenser C3 which by-passes a section of the resistor 61.

A by-pass condenser C4 is also provided for the resistor R2 and connected to cathode of tube T1. In general, the tube T1, as the input stage of the radio frequency amplifier, may be adjusted with relatively high negative bias so that it will be subject to the controlling effect of the automatic volume control. On the other hand, the tubes T2 and T3 may carry higher current values, as determined by the proper choice of their screen grid potentials, than either the tube T1 or the tube D, so that the sums of the plate current of these latter two tubes will be equal to the electronic current of tubes T2 and T3. However, it is also possible to bring in additional current in the detector tube D by means of a separate resistor (not shown) similar to resistor R5 of Figure 3.

I have shown in Figure 8, an alternative ar-

rangement utilizing three tubes, T1, T2, and T3, as a series radio frequency amplifier with a tuned circuit S1 for coupling, and have also shown another tuned circuit S2 coupled to the circuit S1 and connected as input to a detector tube D, the input leads being provided preferably with a grid condenser 67 and grid leak 68. The detector D may form the first of another series amplifier comprising tubes T5 and T6, which together with D, form a series amplifier connected through the primary 69 of a coupling transformer 70. The secondary 71 of said transformer may be either utilized directly on a loud speaker or connected to a further power amplifier tube P. The connection of this power amplifier may be from the positive lead 1 to the output terminals 13 and 14 and to the plate 12. A resistor R4 is connected to the cathode 11 and to negative lead 2. The by-pass condensers C1 and C2 may also be provided. The return lead of the secondary 71 may be connected to the negative lead 2. The resistor R4 is then chosen to give the proper grid bias to the power tube.

I have shown in this diagram two grid biasing resistors R3 and R3', of which R3 may be used exclusively for control grids and R3' exclusively for the screen grids, or as an alternative, R3 may be used for all connections of the chain T1-T2-T3 operating at radio frequency, while the resistor R3' may be used for all the grid connections of the chain D, T5 and T6 of the series audio frequency amplifiers.

The preferred arrangement, as shown, has all of the screen grids connected to R3'. The negative lead of this resistor R3' is brought to a tap point 72 on a resistor 73, the latter being a by-pass resistor to the detector tube D. A condenser 74 is attached between the point 72 and the negative lead 2, and is chosen of such a value that in conjunction with the part of resistor 73, which it by-passes, it would have a relatively long time constant and thus serve as an automatic volume control. A resistor 75, connected to the cathode 76 of tube D, provides the necessary grid bias for the detector D. The volume control is accomplished in this case by the variation of the screen grid potentials.

Thus, it will be seen that an excessive signal being demodulated by the detector D causes a considerable increase in its impedance and therefore shifts the excess of current which tends to remain constant on account of the presence of the coupling transformer 69 to the resistor 73, thus placing a higher voltage on the condenser 74. If the excessive signal is merely a transitory note, the original potential of condenser 74 will not be affected to any great extent, as the time constant of the combination is long, but if the excessive signal persists, then the potential of condenser 74 is raised, and consequently, the potential on all of the screen grids.

In general, the operation of screen grids is such that a change of the potential of the screen grid changes the amplification constant of the tubes. In the particular example illustrated, it is assumed that a rise in the screen grid potential will reduce the amplification, in accordance with the theory discussed in connection with Figure 6. If, however, tubes are utilized which have the opposite properties, or if a detector is used which has an increase of plate current with excess signal, then the connection of condenser 74 should be across a section of resistor 75, rather than 72. Also, the by-pass resistor 73 may be connected to any of the plates of

tubes T5 or T6 if higher volume control potentials are necessary or instead of a by-pass condenser 74 an inductance in series with 73 may be used to give the necessary time constant or even the inductance 69 may give the necessary time constant in combination with tube impedance of tubes T5, T6 and D, so that with the detector of the second type, the screen grids may be supplied from one of the intertube connections, or for each tube from its corresponding plate circuit by a suitable high resistance.

The system is, therefore, seen to possess great flexibility with regard to volume control. It may be controlled either by the variations of the screen grid potential, as illustrated in Figure 8, or by the variation of the bias of the input circuit of tube T1, as illustrated in Figures 3 and 7, or by the variation of the control grid potential of all of the amplifier tubes by connecting R3 of Figure 8 to the condenser 74 rather than the resistor R3'. Moreover, the volume control may be adapted to the particular characteristics of the tubes; that is, depending on whether the amplification constant rises or falls with the corresponding rise and fall in the potential of the control elements and whether the detector impedance rises or falls with excess signal.

The circuit of Figure 8, which shows two coupled circuits S1 and S2, may be arranged to have the same type of response characteristics as that illustrated in Figure 3a, by slightly staggering the resonant frequencies of these two circuits. It is evident, however, that the condenser 77 of the circuit S2 may be omitted and also that any other coupling arrangement, such, for instance, as illustrated in Figure 3, may be used for coupling the radio frequency series amplifier to the detector tube D.

Referring to Figure 9, I have shown an arrangement in which a part of the series amplifier is used as resistance coupling element at a different frequency. The detector tube D is connected below the series amplifier comprising the tubes T1, T2, and T3 (that is, at its negative end), and supplied with radio frequency energy from the filter circuit S1 by means of a coupling condenser 7 and grid leak 8. In this case, the changes of audio frequency impedance of the tube D are further amplified in tube T1 and will have an amplified audio frequency potential. Audio frequency by-pass condensers, 85 and 86, extend respectively from the cathode of tube T2 to its grid, and from the cathode of tube T3 to their respective grids.

Radio frequency chokes, 87 and 88, are connected in series with the condensers 85 and 86. By this means, the tubes T2 and T3 are held with invariable impedance at audio frequency, while at radio frequency they are free to undergo the changes of impedance in accordance with the description of Figure 6 and the general theory of series amplifier.

Since the impedance of tubes T2 and T3 remains constant with respect to audio frequency, they will act as a resistance coupling element for the changes in impedance of tube D and tube T1, and a direct coupling may be applied from the plate of tube T1 to the grid 9 of the power tube P, or some other amplifier. A choke coil 89 is provided at this coupling lead to stop the flow of radio frequency current into the power amplifier. The connections of the power amplifier P may be the same as in Figure 1.

The resistor R4, in series with the cathode 11 of tube P, may have a value of resistance sufficient

to provide a potential of the cathode of tube P above the potential of the grid 9 of this tube, by the necessary grid bias amount for the proper operation of tube P. I have also shown by-pass condensers 63 and 64 which perform the same functions as the same elements in Figure 3.

Referring to Figure 10, I have shown an alternative connection for the detector tube D, in this case above the series amplifier, consisting of tubes T1, T2, and T3. The tube D is connected on the outside of the tuned circuit S1, but in series with the tubes T1, T2, and T3 and with resistor 90 between its cathode and the circuit S1, to provide the proper grid bias potential for the detector tube.

The grid 91 is connected to the plate of tube T3 by means of a grid condenser 92 and grid leak 93, although in some cases, direct connection may be used with sufficient detection by the so-called method of plate rectification utilizing the bend of the characteristic curve. The plate of the tube D is shown connected to the audio frequency coupling device; in this case a choke coil 94, and to a further coupling condenser 7 with a grid leak 8 to the grid 9 of the power amplifier P.

An alternative method of volume control is shown which comprises the by-pass condenser 95 in series with a resistor 96 preferably with asymmetric characteristic, the latter having across its terminal a condenser 97, and forming with it a combination of large time constant in which variations of potential at audio frequency across the choke coil 94 and detector tube D, are impressed. If the signal becomes excessive, these variations will introduce a change in the potential across resistor 96. The potentiometer R3 being connected through resistor 96 to the positive lead 1, any change in the potential of resistor 96 will be communicated to the potentiometer R3. The arrangement in this respect therefore, becomes similar to that of Figure 8, where the volume control was used for varying the potential of the screen grids, only in this case, not alone the screen grid but also the control grids of tubes T2 and T3 are also varied.

Since an excessive radio frequency potential will cause an increase in the impedance of tube D and a consequent lowering of the average accumulated potential across the resistor 96, it will result in the relative rise of potential on the potentiometer R3, and consequently higher control potential applied to the screen grids of tubes T1, T2, T3, and D. As has been discussed in connection with Figure 8, such a rise in the screen grid potential means a lowering of amplification constant, and hence a reduction in the signal.

Referring to Figure 11, I have shown an arrangement of series amplifier utilizing a so-called super-heterodyne connection. The general operation of a super-heterodyne includes the conversion of the received signals into another frequency known as intermediate frequency, and amplification at this intermediate frequency for further demodulation into audio frequency.

In Figure 11, the antenna 34 with a coupling coil 33 and a ground connection 35 is shown. The coil 33 is coupled to a tuning circuit comprising coil 31 and a variable condenser 32. The tuned circuit forms a part of the input circuit of the first tube of a series amplifier, consisting of tubes T1, T2, T3, and T4. The cathode 3 of the tube T1 is connected through a coupling coil 100 and a bias resistor R2 with a by-pass condenser 57, to the negative supply lead 2. The coil 100 is coupled to another coil 101, which may be the output coil of an oscillator 102, the connections of which

are not shown, but which may be of any standard type of oscillator, including a variable condenser 103. This variable condenser may be arranged for a common control 104 with the variable condenser 32, these condensers being designed, as is usual for super-heterodyne sets, to have values of capacities at all settings, such as to produce a definite difference of frequencies in the tuned circuit 31—32 and the oscillator 102. Thus, heterodyne beats are introduced in the grid 4 of tube T1 and amplified through series amplifiers T2, T3, and T4.

I have shown the grid 15 of tube T2 connected to a grid condenser 105 and a grid leak 106, the purpose of which is to demodulate the heterodyne currents of the tube T1 impressed on the cathode of tube T2, so as to leave substantially only intermediate frequency on the subsequent tubes T2, T3, and T4. I have shown, moreover, a by-pass condenser 107 from the plate of tube T2 and a radio frequency choke coil 108 between the plate of tube T2 and the cathode of tube T3. The object of the by-pass condenser 107 and the choke 108 is to localize the radio frequency oscillations to the tubes T1 and T2 and permit intermediate frequency variations only to pass on to tubes T3 and T4. I have also shown a coupling element in series with the plate 109 of tube T4, consisting of a tuned circuit consisting of inductance 110 and a condenser 111 arranged to be within the frequency range of the intermediate frequency. The coil 110 is coupled through the coil 112 to another tuned circuit comprising the coil 112 and condenser 113 and the combination of the two above tuned circuits, forms the necessary coupling element with a high impedance over the intermediate frequency range necessary for successful transmission of the modulated signals; that is, it may be a range of frequency of 10 kilocycles, say, around an intermediate frequency of 100 kilocycles, or whatever other intermediate frequency is chosen.

The design of such a filter is well known in the art and any alternative construction may be utilized. I have shown the output of the intermediate frequency coupling element connected from the coil 112 to the grid 114 of the second detector D, which demodulates the intermediate frequency into audio frequency. To assist demodulation, a grid condenser 115 and grid leak 116 may be used, but this is not always necessary. The other lead from coil 112 is shown connected between a grid bias resistor 117 in series with the cathode 118 of tube D and a volume control tube 119 which, as is shown, may act as a rectifier for changes in the plate current of tube D.

The grid 120 and plate 121 of the tube 119 are shown connected together and by-passed to the cathode 122 of the same tube, by means of resistor 123 and condenser 124. The combination of tube 119, resistor 123, and condenser 124, is designed for a large time constant so as to give the variations of voltage, only due to sustained excessive signals. Thus, an excessive signal coming in at detector D would result in an appreciable diminution of the average plate current of this tube and a consequent reduction of the potential across the rectifier tube 119 and the resistor 123. A tap 125 on resistor 123 applies the reduced potential to the control grid 15 of tube T2, which acts as a first detector and, by lowering its potential, will reduce the effectiveness of this tube as a detector and as an amplifier, so that

the signal amplified by tubes T3 and T4, and detected by tube D, is also reduced.

A condenser 126 is shown by-passed from the tap 125 to the negative lead 2. The detector tube D may be coupled to a power amplifier tube P by means of direct connection from its plate 127 to the grid 9 of the power tube, and a plate coupling resistance R5, similar to Figure 3, may be supplied. The power tube may be connected in any desired manner, for instance, as shown in Figure 3, and is not specifically illustrated in this diagram. Although this diagram shows ordinary three-electrode tubes used, it is quite evident that screen grid tubes could be similarly utilized and that such screen grid tubes could also be connected to the potentiometer R3, which is used for the series amplifier, in exactly the same manner as has been shown in the several previous figures.

Referring to Figure 12, an alternative arrangement is shown in which the series amplifier consisting of tubes T1, T2, T3, and T4 may have for tube T1, a tube with a space charge grid 130, in addition to the control grid 4. In this case, I can utilize this space charge grid to produce oscillations in the tube T1, by connecting an oscillator circuit comprising variable condenser 103 and a coil 101 in the circuit of the grid 130, a coil 100 coupled with 101, and a by-pass condenser 131 in the circuit of the plate 5 of tube T1. Thus, while the input circuit 31—32 applies a potential at incoming frequency to the control grid 4, the space charge grid 130 at the same time applies an oscillation of a frequency determined by the oscillatory circuit of condenser 103 and coil 101.

I have shown a grid bias resistor R2 with a by-pass condenser 57 in the input circuit and a high resistance by-pass 132 in parallel with condenser 131. This combination will act effectively as a demodulating circuit, so that the tubes T2, T3, and T4 will receive substantially only intermediate frequency oscillations and will amplify such oscillations, as a series amplifier, due to the presence of the filter circuit consisting, in this case, of three tuned circuits, S3, S4, and S5, in series with the plate 109 of tube T4 and on account of the connections from the control grids of tubes T2, T3, and T4 to the potentiometer R3.

The output from the filters S3, S4, and S5 extends through a condenser 7 to a second detector tube D, which converts the intermediate frequency signals to audio frequency and has a grid leak resistance 133 and the following volume control arrangement. A rectifier tube 119, similar to Figure 11, is connected in series to the cathode 118 of tube D, and a tap point 125 on a by-pass resistor 123 is used to supply the grid bias to the grid 114 of the tube D, via the grid leak 133. A by-pass condenser 126 is supplied on the volume control and also a by-pass condenser 124 in parallel with the rectifier tube 119. This condenser is arranged with the resistor 123 and the impedance of tube 119 to have the necessary long time constant. The tube D may have an intermediate frequency by-pass condenser 134 from plate 127 to cathode 118 and a choke coil 135, suitable to block off the intermediate frequency.

As a result, only variations of audio frequency will reach a further amplifier tube T5 in series amplifier connection with the tube D1. The grid 136 of tube T5 may be supplied with a constant potential from the common potentiometer R3. The output of tube T5 and, if necessary, of a further amplifier tube T6 (not shown) connected and in series with it, is obtained from a coupling transformer 70, which may be similar to that of

Figure 8 and lead further into a power amplifier stage (not shown). It will be seen that in this case the volume control arrangement is applied to the second detector, while in Figure 11 the volume control was applied to the first detector. Either of these arrangements may have advantages, depending on the particular design of the amplifier. Thus, the connection of Figure 11 gives a more effective volume control over a wider range of amplitudes, while Figure 12, with a simpler oscillator arrangement, gives also a simpler volume control arrangement.

I have shown in Figure 13 another alternative arrangement in which the series amplifier T1, T2, and T3 uses the tube T1 as a radio frequency input tube, exactly as, say, in Figure 3, and the tube T2 as an oscillator. The tube T2 has its grid 15 connected to a tuned circuit comprising variable condenser 103 and a coil 101. A tickler coil 100 is connected to the anode 6' of tube T2. A back coupling condenser 131 is used to connect the tickler coil back to the cathode 16 of tube T2. A grid bias resistor 136 may be supplied, if necessary, for the tube T2, used as oscillator.

The variable condenser 103 is shown to have a common control 104 with the variable condenser 32 of the input circuit 31—32, and also with the coupling circuits S1 and S2, which are arranged in exactly the same manner as the circuits 31—32 and 103—100, to give the frequency response to the two heterodyning frequencies in the series amplifier T1, T2, and T3. Thus, the heterodyning frequencies are permitted to be freely amplified up to the anode 6 of tube T3 and at the same time, certain demodulation to intermediate frequency will take place in this series amplifier.

This demodulation will impress the potential at intermediate frequency only to a further series filter of intermediate frequency, which may be exactly similar to that of Figure 11 and consisting of a primary 110 with condenser 111 and a secondary 112 with a condenser 113. I have shown the output of the secondary 112 applied to a further intermediate frequency series amplifier consisting of tubes T4, T5, and T6, with series coupling circuits S3 and S4, which are arranged to have a high impedance over the modulated intermediate frequency range, that is, the same range for which the first intermediate frequency filter of coil 110 with condenser 111 and coil 112 with condenser 113, were designed.

Thus, the intermediate frequency signals will be freely amplified through the second series amplifier and simultaneously demodulated, resulting in audio frequency changes of impedance, which may be directly impressed upon a series audio frequency transformer 70 with an intermediate frequency by-pass condenser 137. The output coil 71 of transformer 70 may be applied to further audio frequency amplifier of any suitable design and supplied, for instance, with a volume control terminal 138 and the supply terminals 139 and 140, connected respectively to positive lead 1 and negative lead 2.

The volume control terminal 138 may be used, for instance, for controlling the potential of the screen grids of tubes T4, T5, and T6, by means of potentiometer R2' in an arrangement similar to that of Figure 8. I have supplied a choke coil 139', in order to prevent any changes of radio or intermediate frequency that may exist in resistor R3' from reaching the volume control terminal 138. As it is necessary to use tube T4 partly as a detector at audio frequency, I have

supplied, moreover, a grid bias resistor 140 in the cathode circuit of this tube, together with a by-pass condenser 141 and a plate by-pass 142, which, however, may be omitted and also a screen grid by-pass condenser 143, which may also be omitted, without greatly affecting the operation of this device. A choke coil 144 serves furthermore, to prevent any changes at radio frequency from reaching the intermediate frequency amplifiers T4, T5, and T6.

In Figure 14 there is shown a schematic arrangement to illustrate in a general way the manner in which a series amplifier can be used in a suitable chain of amplifiers arranged for different frequency ranges in somewhat similar manner to the chains of parallel connected amplifiers operating at different ranges. Thus, tubes T1, T2, T3, and T4 operate as radio frequency series amplifiers, while the tube T3 at the same time may act as an oscillator similarly to the connections of tube T2 of Figure 13, except that the grid 18 of tube T3 is shown connected directly to the potentiometer R3 and the oscillator circuit of condenser 103 and coil 101 is connected through condenser 145 with the cathode lead of tube T3. In this way, the tube T3 will act simultaneously as an oscillator and also as a part of the radio frequency series amplifier.

A radio frequency coupling element or filter RF is connected between the tubes T4 and T5, which may be exactly similar to the radio frequency filter of Figure 13, consisting of S1 and S2. A connection from the plate 109 of tube T4 is made to the grid 146 of tube T5, and while this connection does not indicate by the presence of grid condenser or grid leak that the tube T5 will act as a detector, yet, by proper choice of the grid bias of tube T5, such detection may be obtained.

By-pass condenser 147 returns the intermediate frequency variations on the outside of the radio frequency filter back to the negative lead 2. The tubes T5, T6, and T7 are shown to operate at intermediate frequency as a series amplifier with an intermediate frequency filter IF connected to the plate 148 of tube T7. The intermediate frequency filter may be of any known type, for instance, such as is shown in Figure 12 or 13. The plate of tube 148 is shown connected to the grid 149 of tube T8 and again, the tube T8 may act as a detector to audio frequency. The variations of the latter frequency are by-passed through condenser 150 to the negative lead 2. The tubes T8, T9, and T10 may act as an audio frequency series amplifier with an audio frequency filter marked AF, the output terminals of which—151 and 152—may lead either to utilization as loud speaker, or to further amplifiers. The audio frequency filter is connected to the plate 153 of tube T10 and to the positive lead 1, and the potentiometer R3 is shown connected directly between the positive lead 1 and the negative lead 2 and has taps to the different control grids, except to the grids of the tubes which are used as detectors, such as tubes T5 and T8. It is evident that screen grids could be used just as well, or space charge grid tubes could be used, and the connections to such screen grids or space charge grids will be again to the common potentiometer R3 or to other potentiometers similar and parallel to it.

While the particular diagrams illustrate different connections of amplifiers applied to receiving circuits, it is quite possible and evident to one skilled in the art that similar or identical diagrams may be applied also to transmitting

circuits. Thus, for instance, referring to Figures 11 to 14 which show the introduction of special oscillations into one of the tubes of a series amplifier, the oscillations which are introduced may be used for the purpose of transmitting and the oscillator itself, either of the type shown in Figure 11 or of the type shown in Figures 12 to 14, may be controlled by special frequency controlling means such as crystals or tuning forks, and modulated by signalling impulses such as telephonic or telegraphic signals.

When used for transmitting purposes, the construction of electric valves in the series amplifier may sometimes be modified to advantage. For instance, instead of increasing the current of such valves for higher power, the potential may be increased as the series amplifier is particularly effective in amplifying potential variations. Also, for such purposes it may be desirable to utilize by-path circuits on some of the valves which carry relatively lower current than the highest powered valve.

Other uses of this type of amplifier include all of the uses to which the present type of power amplifiers are applied. Thus, for instance, this type of amplifier can be used for picture transmission or for transmission of television signals, or for amplifying of telephonic currents in telephone networks. Moreover, the various factors which enter into the operation of such amplifiers of the parallel type are clearly brought out in this specification as applied to series amplifiers, and it is a part of my invention to provide means for utilizing such operating factors as volume control, tuning, heterodyning, and so forth, in a series amplifier.

While I have illustrated a number of modifications of the uses of series amplifier and some general and theoretical diagrams and arrangements, such as Figures 2, 6, and 14, which illustrate schematically the method of operating such amplifiers, I do not wish to be limited to the particular circuits or theoretical consideration outlined in the specification, except as defined in the appended claims.

What I claim is:

1. In an amplifying system, comprising a plurality of valves, each having cathode, anode and control electrodes, said valves being arranged in series with the anode of one valve being connected to the cathode of the succeeding valve; a common coupling means having a fixed impedance connected to the anode of the last valve; a common source of operating potential supply for said valves arranged so that substantially the same current flows through said valves and said coupling means in series; means for applying input potential variations to the first valve of the series; means for maintaining the control electrodes of said valves at predetermined fixed potentials; means including circuit connections for deriving output potential variations developed by said coupling means, said coupling means being designed to present high impedance to said input potential variations.

2. In an amplifying system, comprising a plurality of thermionic valves each having cathode, plate and grid electrodes, said valves being arranged in series with a plate of one valve being connected to the cathode of the succeeding valve; an impedance coupling means connected in series with the plate of the last valve; a source of anode potential supply connected to said valves and said impedance so that the same current flows through said valves and said impedance; means for sup-

- plying input potential variations to the grid of the first valve, means for maintaining the control electrodes of said valves at predetermined fixed potentials; said coupling means being designed to present high fixed impedance to the frequency range of said input potential variations, and means for deriving amplified output potential variations developed by said impedance means.
3. In an amplifying system as claimed in claim 2 in which said impedance means consists of a high ohmic resistance for supplying amplified potential variations in accordance with a broad range of input potential variations applied to said system.
4. In an amplifying system as claimed in claim 2 in which said impedance means consists of a transformer designed to present high impedance to a predetermined range of input frequencies applied to said system.
5. In an amplifying system as claimed in claim 2 in which said impedance means is comprised of an audio frequency transformer designed to have high impedance with regard to the desired input audio frequency band to be applied to said amplifying system.
6. In an amplifying system as claimed in claim 2 in which said impedance means is comprised of a choke coil designed to present high impedance to a predetermined range of frequencies to be applied to and amplified by said system.
7. In an amplifying system as claimed in claim 2 in which said impedance means is comprised of an electric filter designed to present high impedance to a predetermined band of frequencies to be applied to and amplified by said system.
8. In an amplifying system as claimed in claim 2 in which said impedance means is comprised of a multiple tuned circuit, resonant to the frequency of input potential to be applied to and amplified by said system.
9. In an amplifying system as claimed in claim 2 including means for maintaining the grids of said valves at a fixed operating potential.
10. In an amplifying system as claimed in claim 2 including a potentiometer and tap connections from said potentiometer at definite points thereof to the grid electrodes of said valves for maintaining fixed grid potentials during operation.
11. In an amplifying system as claimed in claim 2 including a potentiometer connected across said potential supply source, and tap connections from points of said potentiometer to the grid electrodes of said valves, for maintaining fixed grid potentials during operation.
12. In an amplifying system as claimed in claim 2 in which a plurality of groups of series amplifying valves are provided with impedance coupling means for each group designed for amplification of a different predetermined range of frequencies, means for connecting said groups in series and for changing the operating range of frequencies of one group into the range of frequencies of the succeeding group for successive amplification of signals applied to the input of the first group, to be translated into amplified signals supplied from the last group.
13. In an amplifying system as claimed in claim 2 comprising a plurality of groups of series amplifying valves, each group including an impedance coupling means designed for a different predetermined range of operating frequencies, heterodyning means connecting one group in series with the succeeding group for changing the operating frequency of one group into the operating frequency of the succeeding group, for amplifying high frequency input signals applied to the input of the first group and to be delivered from the output of the last group and a common operating potential source, supplying all of said groups in series.
14. In an amplifying system as claimed in claim 2 in which two impedance means designed each for a different predetermined range of frequencies are provided, and means for feeding back output potential variations in accordance with one range of frequencies and obtained from one impedance means to the input of the series to effect a multiple amplification by the same series of valves and said second impedance means.
15. An amplifying system comprising a plurality of discharge devices each comprising a cathode, plate and grid electrode; a source of current supply; a coupling element of fixed high impedance with respect to the signalling current variations to be amplified; said devices, said coupling element and said source being connected in series with the plate of one device being directly connected to the cathode of the succeeding device; means for applying input current variations to the grid of the first discharge device; means for deriving output potential variations from said coupling element; and means for stabilizing the direct grid potentials of said discharge devices.
16. An amplifying system; a plurality of discharge devices, each comprising a cathode, plate and grid electrode; a source of current supply; a high ohmic fixed resistance; said devices, said resistance, and said source being connected in series with the plate of one device being directly connected to the cathode of the succeeding device; means for applying input current variations to the grid of the first discharge device; means for deriving output potential variations from said resistance; and means for stabilizing the direct grid potentials of said discharge devices.
17. An amplifying system; a plurality of discharge devices, each comprising a cathode, plate and grid electrode; a source of anode current supply; a coupling element designed to present a high fixed impedance to audio frequency currents; said devices, said coupling element and said source being connected in series with the plate of one device being directly connected to the cathode of the succeeding device; means for applying audio input currents to the grid of the first discharge device; means for deriving output potential variations from said coupling element; and further means comprising a potentiometer connected across said source and having tap connections to the grids of said discharge devices for maintaining constant direct grid potentials.
18. An amplifying system; a plurality of discharge devices, each comprising a cathode, plate and grid electrode; a source of anode current supply; a resonant circuit designed to present high impedance to high frequency currents to be amplified by said system; said devices, said resonant circuit and said source being connected in series with the plate of one device being directly connected to the cathode of the succeeding device; means for applying high frequency input currents to the grid of said first discharge device; means for deriving output potential variations from said resonant circuit; and further means comprising a potentiometer with tap connections to the grid electrodes of said devices for maintaining constant direct grid potentials.

19. An amplifying system; a plurality of discharge devices, each comprising a cathode, plate and grid electrode; a source of anode current; a resonant circuit designed to present high impedance to high frequency currents to be amplified by said system; said devices, said resonant circuit and said source being connected in series with the plate of one device being directly connected to the cathode of the succeeding device; means comprising a potentiometer with tap connections to the grids of said devices for maintaining constant direct grid potentials; further means comprising an impedance bridge supplied from said resonant circuit and provided with tap connections to the electrodes of said devices for maintaining proper high frequency potentials thereat; and means for applying high frequency input potential to the grid of the first device and for deriving output potential from said resonant circuit.

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