

Sept. 24, 1940.

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2,215,796

HIGH FREQUENCY CIRCUIT ARRANGEMENT

Filed April 26, 1937

2 Sheets-Sheet 1

Fig. 2

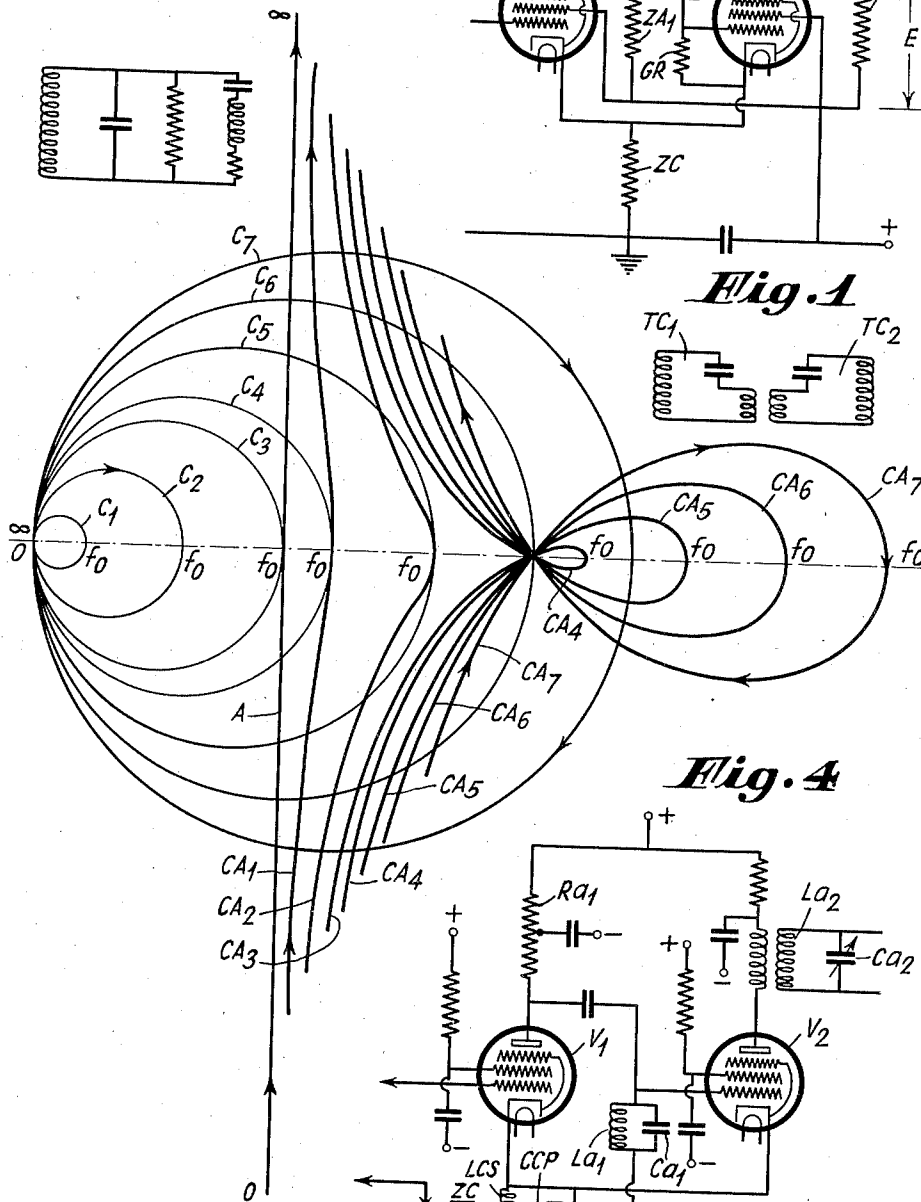


Fig. 3

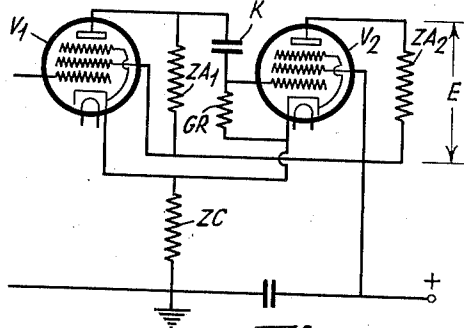


Fig. 1

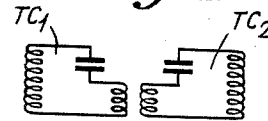
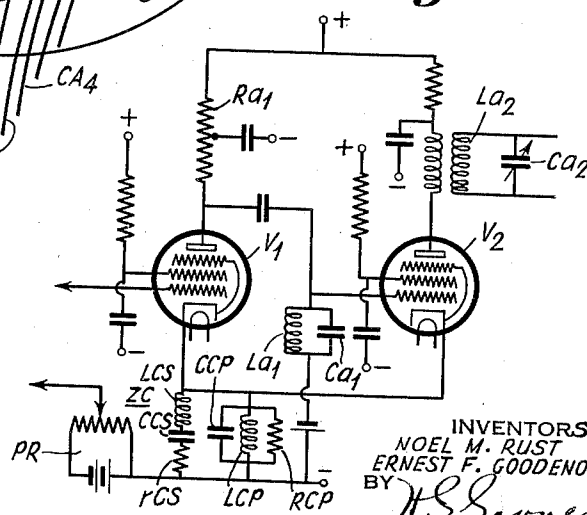


Fig. 4



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2 Sheets-Sheet 2

Fig. 5

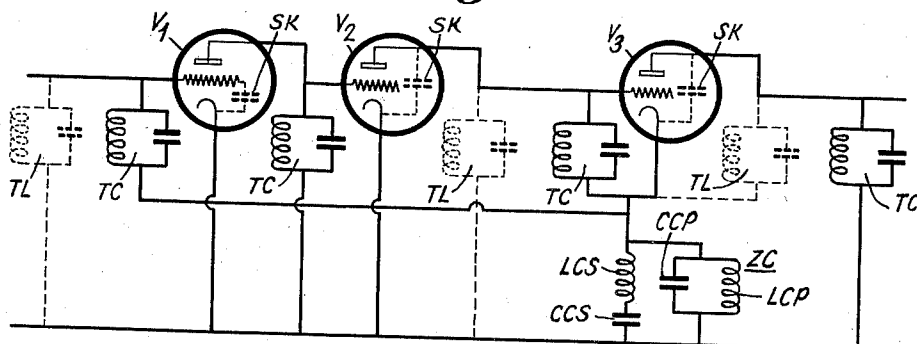


Fig. 6

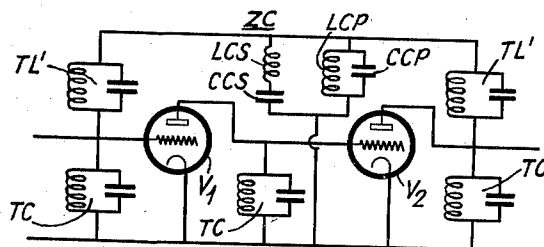


Fig. 7

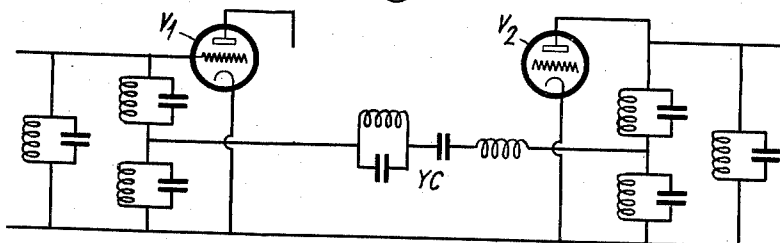


Fig. 8

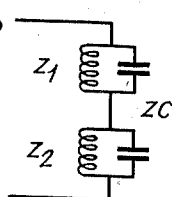
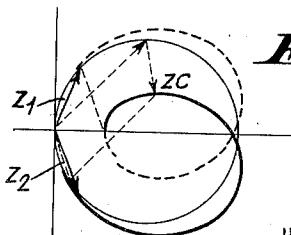


Fig. 9



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HIGH FREQUENCY CIRCUIT ARRANGEMENT

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6 Claims. (Cl. 179—171)

This invention relates to high frequency electrical circuit arrangements and more particularly to circuit arrangements having band-pass characteristics.

5 The object of the invention is to provide improved circuit arrangements which will pass a desired predetermined band of frequencies either without the introduction, as respects any frequency in the band, of a phase change which is
10 seriously different from that introduced for any other frequency in the band or with the introduction in different circuit elements of the arrangement of phase changes which are related in a definite and predetermined manner so that the
15 interactions occurring throughout the arrangement balance and a substantially constant relationship between output and input voltage is obtained over a relatively wide frequency spectrum. In some cases where high gain and uniform
20 amplitude response are the main desiderata it may be advantageous to allow the phases to "slip" towards the ends of the pass range in order to satisfy the said main requirements.

25 The invention is illustrated in and will be explained in connection with the accompanying diagrammatic and graphical drawings.

The usual type of band pass filter as at present in common use in radio receivers and for similar purposes consists essentially of a plurality of
30 resonant circuits coupled in effective cascade with one another. For example, a very well known form of band pass filter shown in Figure 1 comprises two loop circuits each consisting of a
35 coil in series with a condenser and a small coupling coil, the two coupling coils being magnetically coupled. Such a filter consists in effect of two tuned circuits TC1, TC2, coupled in cascade and although there are very many known forms of band pass filter, the majority—especially
40 those suitable for radio and other high frequency working—consist of more or less complex variations of the typical circuit just described; i. e., they consist of a plurality of cascaded resonant circuits.

45 A characteristic of an arrangement consisting of a plurality of cascaded tuned circuits is that phase shift effects are multiplied in the cascade series and this characteristic introduces a defect which imposes serious limitations upon the purposes for which the filter can be satisfactorily
50 employed. The result of this characteristic is that although the band pass curve of the filter may be satisfactory in the sense that the attenuation or gain is approximately the same for all

frequencies in the band to be passed the phase shift produced is very seriously different for the different frequencies in that band and it is this defect that introduces the limitations referred to. For example a known band pass band filter of the cascaded tuned circuit type cannot be satisfactorily employed for reaction or feed back purposes in cases where it is required that the reaction shall be approximately the same throughout a desired band of frequencies, for owing to the
10 different phase shifts produced the result will be—if such a filter is included in the feed back energy channel—that reaction will be greatest for some one frequency and adjacent frequencies and will be much less for other frequencies in the band.

The object of this invention is to avoid the above mentioned defect and to provide filters which, while presenting band pass attenuation or gain characteristics, produce approximately or
20 nearly the same amounts of phase shift for all frequencies in the band.

According to this invention a band pass filter is constituted by a compound impedance network including a plurality of resonant circuits
25 which are not in cascade and which are so dimensioned that at (or near) the limits and at the mid-frequency of the desired band pass, the overall impedance of the network is resistive, while, as regards phase shift effects, the effects due to each individual resonant circuit is, over the
30 desired band pass, annulled or approximately annulled at least over the major portion of the band pass by those due to the other resonant circuit or circuits.

35 It is possible to regard the invention—at any rate in its preferred embodiments—as providing band pass filters wherein the "humped" attenuation characteristic of a tuned circuit is transformed into a more or less flat-topped band pass characteristic by means of another tuned circuit having a "dip" where the "hump" of the first characteristic occurs, so that the net effect of superimposing the two characteristics is to give
40 a band pass resultant.

45 There are, broadly speaking, two main ways of carrying the invention into effect. In one way—the preferred way—a parallel resonant circuit is shunted by a series resonant circuit tuned to the same frequency (the central frequency of the desired band) and the admittance (at resonance) of the series resonant circuit is made more than the admittance (at resonance) of the parallel resonant circuit. In the other main way
50
55

of carrying out the invention two parallel resonant circuits in series are employed, one being tuned to one limit frequency of the desired band and the other being tuned to the other (the root of the product of these limit frequencies being, of course, equal to the mid-frequency) and the admittance of each circuit (at resonance) is made equal to that of the other. In the preceding description it has been assumed, for the sake of simplicity, that in each case the filter comprises only two resonant circuits, but, as will be apparent later, the invention may be embodied in more complex filters.

In order that the invention will be the better understood there will now be described a simple form of filter in accordance with the invention and at the same time the underlying theory employed in its design will also be set forth.

Referring to Figure 2, if the frequency applied to a parallel tuned circuit be varied in the admittance locus of the circuit may be represented by a vertical straight line A rising from frequency 0 to frequency ∞ and passing through a resonance frequency Pf_0 . If the frequency of a series resonant circuit be varied the admittance locus of the series circuit may be represented by a circle, such as $C1 \dots C7$ upon a horizontal diameter at one end of which are frequencies 0 and ∞ and at the other end of which is the resonance frequency Sf_0 (the direction along the locus is assumed clockwise). If a series resonant circuit resonant at Sf_0 be shunted by a parallel resonant circuit resonant at Pf_0 , and $Sf_0 = Pf_0$, and if the resistance SR of the series circuit equals the resistance PR of the parallel circuit, the admittance circle for the series circuit may be drawn to the left of and tangential to the admittance line for the parallel circuit, the circle touching the line at the frequency $Sf_0 = Pf_0$. This is the case shown in Figure 2 by the circle $C3$ and line A. For the sake of simplicity this frequency will hereinafter be termed simply f_0 . The diameter joining the frequencies 0 and ∞ (at one end) and the frequency f_0 (at the other end) on the circle, is, of course, at right angles to the vertical admittance line A. The combined or resultant admittance curve will be a peaked curve $CA3$ to the right of the admittance line rising from minus infinity on that line (corresponding to zero frequency) to a sharp peak at f_0 (on the prolongation of the horizontal diameter of the circle) and then moving up the said admittance line to ∞ (corresponding to infinite frequency). If the admittance

of the series circuit at resonance is less than that

$$\left(\frac{1}{PR}\right)$$

of the parallel circuit at resonance, the circle will not touch the line and the peak of the combined or resultant curve will be lower and flatter. This is the case for circles $C1$, $C2$ and curves $CA1$, $CA2$. If, however,

$$\frac{1}{SR} > \frac{1}{PR}$$

the circle will cut the line at two points corresponding to frequencies $f1$ and $f2$ and the combined curve will show a more or less elliptical

and symmetrical loop to the right of the point where the peak occurs for the case

$$\frac{1}{SR} = \frac{1}{PR}$$

This is the case for circles $C4$, $C5$, $C6$, $C7$ and curves $CA4$, $CA5$, $CA6$, $CA7$. In other words, the curve crosses over at a point which corresponds to two frequencies $f1$, $f2$ which are symmetrical about the frequency f_0 , that point on the loop, and therefore on the whole curve, which is further from the vertical line corresponding to the frequency f_0 . As will be apparent, if

$$\frac{1}{SR}$$

is not much greater than

$$\frac{1}{PR}$$

this loop will be relatively small and the phase shift occasioned by the whole circuit for any frequency within the band $f1$ to $f2$ will not be seriously different from that occasioned for any other frequency in this band. In the present embodiment of the invention, therefore, a parallel tuned circuit is shunted by a series tuned circuit of the same resonance value but higher admittance at resonance and the circuits are designed so that the operating part of the combined or resultant admittance locus is the resultant loop; i. e. the required band pass in the range $f1$ to $f2$.

In another embodiment of the invention shown in Figure 8 two parallel resonant circuits $Z1$, $Z2$ in series are employed to constitute ZC . One of these circuits is tuned to $f1$ and the other to $f2$ (the limits of the required band pass) and the resistance of both circuits is made the same. As hereinbefore stated

$$f_0 = \sqrt{f1f2}$$

Figure 9 is the related vector representation for Figure 8. The type of vector locus diagram obtained by adding the impedance vectors of the circuits $Z1$, $Z2$ is the inverse of the type of admittance curves $CA1 \dots CA7$ of Figure 1. The circuits $Z1$, $Z2$ are so tuned that at f_0 their vectors are of equal length and of phase angle $\pm \tan^{-1}K$ (say). The circuits of Figures 2 and 8 are identical in effect if $K^2 = n$ where n is the ratio of the admittances of the series and parallel circuits of Figure 2

$$(i. e., n = \frac{SR}{PR})$$

and if the impedance R_0 of each resonant circuit of Figure 8 at its own resonant frequency is $r(1+K^2)$ where $2r$ is the overall resistance of ZC at f_0 . These remarks assume that the effects of stray capacity shunting the arrangement of Figure 8 are negligible. Where high frequencies are in question, however, a third circuit (not shown) may be required to tune out stray shunt capacities and this must be taken into effect. For low values of n however, (i. e., for small loops) this circuit has the advantage that a high overall impedance is readily obtainable owing to the absence of any series circuit.

More complex circuits employing the principles of this invention may be employed. For example a parallel tuned circuit shunted by two series tuned circuits in parallel with one another may be employed the parallel tuned circuit being resonant at a frequency f_0 midway between two frequencies to which the two series resonant

circuits are tuned. The resultant or combined admittance curve for this arrangement may, by designing in accordance with the principles already given, be caused to exhibit a double loop of small size and this loop may be worked over by the desired band of frequencies. An arrangement comprising a series resonant circuit shunted by two parallel resonant circuits in series and resonant at frequencies symmetrically staggered with respect to the resonant frequency of the series circuit is another and practically equivalent, possible arrangement.

One form of reaction amplifier embodying this invention is shown in Figure 3 where two valves, e. g., pentodes in cascade, are employed. Input voltage is applied between control grid and cathode of the first pentode V1 whose anode circuit includes a coupling impedance ZA1 the anode of the first pentode being capacity-coupled by condenser K to the control grid of the second pentode V2. The control grid-cathode circuit of the second pentode includes a grid resistance GR of considerably higher impedance than that of ZA1. The anode circuit of the second pentode includes an impedance ZA2. Reaction is obtained by means of an impedance ZC in the common cathode lead for both valves, the two cathodes being connected together and the two anode circuits being completed through ZC. If g_1 and g_2 be the respective mutual conductances of the first and second valves then the magnification—the ratio of the voltage E across ZA2 to the input voltage e to the first pentode—may be expressed by

$$\frac{E}{e} = \frac{g_1 g_2 Z A_2 (Z A_1 + Z C)}{1 + Z C (g_1 + g_2 - g_1 g_2 Z A_1)}$$

In general ZC will be much less than ZA1 for any set of values which makes the additive expression in the denominator positive and nearly equal to zero. Accordingly to make

$$\frac{E}{e}$$

as large as possible and as constant as possible over a required band, there are two main possible expedients: (1) to make ZA1 aperiodic in nature and use for ZC a filter in accordance with this invention, so that its phase is nearly constant over the band, and (2) to arrange for the product ZC ZA1 to be as nearly constant in amplitude and phase as possible.

If the former expedient is adopted the band pass characteristic will tend to show "humped" sides with a dip between them, but this can be corrected for by suitably choosing the Q value (inductive impedance divided by resistance) for ZA2. The second expedient may be carried into practice by using a tuned circuit for ZA1 and employing for ZC a filter in accordance with this invention in which, however, the "loop" is made rather large, i. e., the admittance of the series resonant portion is made substantially larger than that of the parallel portion. This of course results in materially different phase shifts for the different frequencies in the band but these phase shifts substantially annul those due to the tuned circuit constituting ZA1.

In a practical example of two-stage reaction amplifier as above described, the same circuit was employed first using expedient (1) above and then expedient (2). In this circuit which is shown in Figure 4 the first pentode V1 received its anode feed through a resistance RA1 and the control grid circuit of the second pentode V2 in-

cluded a parallel-tuned circuit consisting of an inductance La1 shunted by a condenser Ca1. Output was taken from the anode circuit of the second pentode V2 through a tuned circuit consisting of an inductance La2 shunted by a capacity Ca2, this circuit being inductively coupled to the said anode circuit. The impedance ZC was a filter comprising an inductance LCS, a capacity CCS and a resistance rCS all in series and shunted by an inductance LCP, a resistance RCP and a capacity CCP. The valves V1, V2, were pentodes as known under the trade designation VMS4 and the mutual conductances of the two valves were equal to one another and to unity. Using expedient (1) the values of the circuit elements were as given in columns I of the table below and using the expedient (2) the values were as given in columns II. In the table Qa1, Qa2, QCP and QCS represent the respective Q values of the tuned circuits La1—Ca1; La2—Ca2; LCP—CCP—RCP; and LCS—CCS—rCS. The band limits f_1 , f_2 were (about) 440 and 460 k. c. respectively, and the gain is given for the frequency f_0 —450 k. c. (about).

	I	II		I	II
La1.....	1,640	97	LCP.....	5.45	6.7
Ca1.....	65	1,300	CCP.....	23,000	18,800
Ra1.....	5,000	12,000	RCP.....	550	1,650
Qa1.....	1.08	44	QCP.....	36	87.5
La2.....	50.5	198	LCS.....	2,000	1,025
Ca2.....	2,500	640	CCS.....	62	123
Ra2.....	5,500	10,000	rCS.....	160	33
Qa2.....	39	18	QCS.....	36	87.5
ZC (f1)/ZC (f0).....	2.2	25.5	Gain.....	45	180

With these arrangements the gain was substantially constant between 440 k. c. and 460 k. c. with rapid cut-off outside this range.

In the above table inductances are in microhenries, capacities in micro-micro-farads; and resistances in ohms. The ratios

$$\frac{ZC(f_1)}{ZC(f_0)}$$

represent the ratio of the filter impedance at f_1 to that at f_0 . These ratios are indicative of the sizes of the "loop." Feed back control was effected by varying the mutual conductance of the first valve by means of a potentiometer PR controlling its grid bias.

The invention is not limited to its application to circuits wherein reaction is obtained by means of feed back impedance in cathode return circuits nor indeed to reaction circuits at all. The most important application of the invention is, however, probably to reaction circuits, e. g., to reaction amplifiers for short wave (6 metre or thereabouts) television receivers and in other cases where good and uniform amplification, supplemented by reaction, is required over a relatively wide band.

In the preceding description it has been stated, for the sake of clearness and sufficiency, that the limits of the pass region are defined by the frequencies f_1 and f_2 where the "loop" crosses over and the impedance is resistive. This statement is accurate enough for most practical purposes, but in the case of small "loops" it is more accurate to define the limits of the pass band as those frequencies at which the impedance vector is at a maximum. These frequencies, though nearly the same as the frequencies f_1 , f_2 at which the "loop" crosses over, are, for small "loops" perceptibly different.

Figure 5 shows a three stage modification of Figure 4 employing three valves V1, V2, V3

(shown as triodes) with tuned anode and grid circuits. All the tuned circuits are marked TC. Reaction is obtained in the same general manner as in Figure 4 by the network generally designated ZC. Where very high frequencies or very high gains are in question the valve self-capacities (indicated by the broken line condensers SK) are of importance and may present "stray" paths of impedances comparable with the normal, intended paths. Difficulties from this cause may be met, as shown in Figure 5, by providing extra coils TL which serve to tune out these valve capacities. Condensers, also in broken lines, are shown in shunt with the coils TL to represent the total capacities (including capacities SK) across the coils TC. These total capacities may be wholly or in part constituted by self and distributed capacities.

In the modified two stage amplifier shown in Figure 6 circuits TL' are employed to tune out the valve self-capacities and the network ZC in accordance with this invention is connected between the common cathode point of the two valves on one side and (through the circuits TL') the grid of valve VI, and the anode of valve V2 on the other. The amplifier of Figure 6 is again very well suited for use in cases where high amplification, or amplification at high frequencies, is required. Another feature of the circuit of Figure 6 is that the network ZC is so connected as to provide positive feed back action alone whereas in the previously described circuits, although the positive feed back action of the network ZC predominates in all cases, there is also a negative feed back action which has to be taken into account in the design. This negative feed back is represented by the product ZC ($g_1 + g_2$) forming part of the expression for

$$\frac{E}{e}$$

already given above in the description relating to Figure 3.

Figure 7 shows a modification in which what may be termed "voltage feed back" is obtained. In Figure 4 (for example) the feed back obtained by virtue of the network ZC in the common cathode leg is dependent upon the product of the current passing through the said network multiplied by the impedance thereof. This feed back may, therefore, be termed "current feed back." In Figure 7, however, there is employed an admittance network (as distinct from an impedance network) between the input circuit of the first valve VI and the output circuit of the second valve V2 and the feed back will therefore now be approximately proportional to the output voltage of the amplifier multiplied by the admittance of the network (generally designated YC). It will be observed that the network YC is (so far as the reactances are concerned) the reciprocal network to the network ZC of Figure 4. For the sake of simplicity in drawing, the coupling impedance between the anode of valve VI and the grid of valve V2 has been omitted. This coupling impedance may, however, be designed in accordance with the principles already given in connection with Figure 4, i. e. it may be aperiodic or it may be such that at resonance (approximately the mid-band frequency) the anode voltage on valve V2 is in phase with the grid voltage on valve VI. Since, at that frequency, YC is non-reactive and of relatively low admittance, a degree of positive feed back takes place. For frequencies adjacent the resonant frequency, the

voltage at the output of valve V2 changes in phase with respect to that at the input of valve VI, but, owing to the dimensioning of the network YC (in relation to the anode and other coupling impedance), this phase change is compensated for just as in the circuits wherein an impedance network (ZC) is employed.

It is important to note that, whether voltage or current feed back is employed, amplitude correction as well as phase correction, is obtainable.

The invention is not limited to the use of the particular forms of "ZC" circuits shown and other forms are available; for example networks as well known per se and consisting of two parallel tuned circuits coupled by mutual inductance or 15 capacity could be used.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed we declare that what we claim is:

1. A thermionic amplifier comprising a plurality of coupled electron discharge tubes, means for feeding back current from one stage to another including an impedance network constituting a band pass filter, said band pass filter including a plurality of parallelly-connected resonant circuits which are so dimensioned that at approximately the limits and at the mid-frequency of the desired band pass the over-all impedance of the network is resistive, while, as regards phase shift effects, the effects due to each individual resonant circuit is, over the desired band pass, annulled or approximately annulled at least over the major, central portion of the band pass by those due to the other resonant circuit.

2. A thermionic amplifier comprising a plurality of coupled electron discharge tubes, means for feeding back current from one stage to another including an impedance network constituting a band pass filter, said band pass filter including a parallel tuned circuit shunted by a series tuned circuit, both said circuits being resonant at approximately the central frequency of the band desired to be passed, the admittance at resonance of the series tuned circuit being more than the admittance at resonance of the parallel tuned circuit.

3. A thermionic amplifier comprising a plurality of coupled electron discharge tubes, means for feeding back voltage from one stage to another including a feed back admittance constituted by a band pass filter, said band pass filter including a plurality of parallelly-connected resonant circuits which are so dimensioned that at approximately the limits and at the mid-frequency of the desired band pass the over-all impedance of the network is resistive, while, as regards phase shift effects, the effects due to each individual resonant circuit is, over the desired band pass, annulled or approximately annulled at least over the major, central portion of the band pass by those due to the other resonant circuit.

4. A thermionic amplifier comprising a plurality of coupled electron discharge tubes, means for feeding back voltage from one stage to another including a feed back admittance constituted by a band pass filter, said band pass filter including a parallel tuned circuit shunted by a series tuned circuit, both said circuits being resonant at or near the central frequency of the band desired to be passed, the admittance at resonance of the series tuned circuit being more than the admittance at resonance of the parallel tuned circuit.

5. A thermionic amplifier system comprising

a pair of electron discharge tubes, means for feeding back energy from one tube to the other including an impedance network constituting a band-pass filter, and means including an impedance in the anode circuit of the first tube for coupling the output of the first tube to the input of the second, said coupling impedance and the feedback impedance being so dimensioned that their product is of substantially constant amplitude and phase over the transmitted frequency band.

6. A thermionic amplifier system comprising a

pair of electron discharge tubes, means for feeding back energy from one tube to the other including an admittance constituting a band-pass filter, and means including an impedance in the anode circuit of the first tube for coupling the output of the first tube to the input of the second, said coupling impedance and the feedback admittance being so dimensioned that their product is of substantially constant amplitude and phase over the transmitted frequency band.

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