Feb. 17, 1942. J. HAANTJES 2,273,519

AMPLIFIER CIRCUIT

Filed June 25, 1940

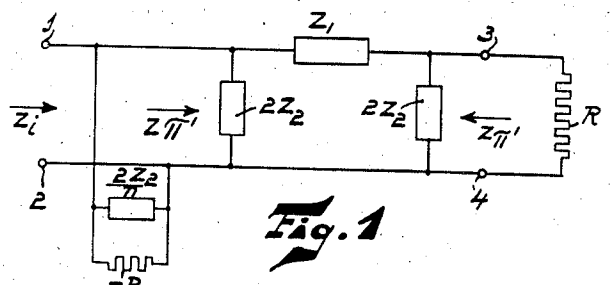

Fig. 1

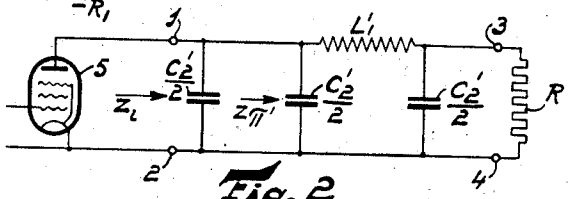

Fig. 2

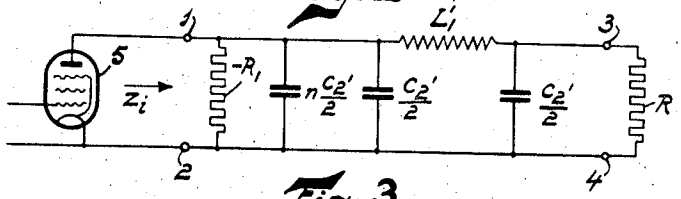

Fig. 3

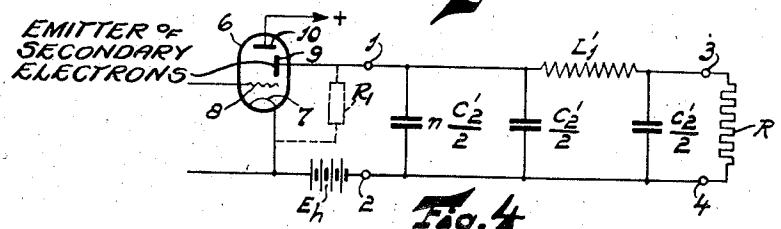

Fig. 4

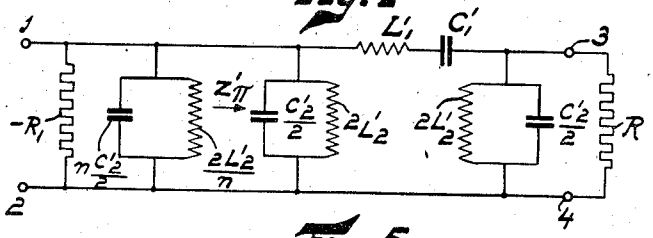

Fig. 5

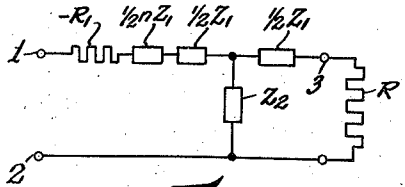

Fig. 6

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AMPLIFIER CIRCUIT

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5 Claims. (Cl. 179—171)

The invention relates to a circuit arrangement which comprises an impedance constituted by the input-impedance of a low-pass or band-pass filter of the π- or T-type respectively.

It is already known to use such impedances in amplifiers such as, for instance, television amplifiers by which a large range of frequencies is to be uniformly amplified. In these well-known circuits the impedance connected in the anode circuit of an amplifying tube is constituted by the input-impedance of a low-pass filter section of the fundamental π-type which consequently consists of an inductance L_1' in the series-branch and capacities $\frac{1}{2}C_2'$ in each of the two shunt-branches. The output terminals are terminated by a resistance which is matched to the image-impedance between the output terminals. In these circumstances the input-impedance corresponds to the image-impedance and this behaves in the transmission band as a resistance whose value increases as the frequency is higher, which consequently would yield an amplification dependent on the frequency. In order to render the absolute value of the input-impedance and consequently also the amplification independent with respect to frequency it has furthermore been proposed already to connect, in parallel with the input terminals, an additional condenser $\frac{1}{2}C_2'$ corresponding to the shunt-condenser of the filter network between these terminals. As will be shown hereinafter the absolute value of the input-impedance of the filter corresponds in this case to the nominal value R of the image-impedance so that the amplification determined by the input-impedance is constant for all frequencies in the transmission band. It appears that the product of the band-width (i. e. the width of the range of frequencies transmitted) and amplification which can be achieved by means of such an amplifier is inversely proportional to the value of the shunt condenser $\frac{1}{2}C_2'$ of the filter network and since the minimum value of this condenser is limited by the anode-cathode capacity of the amplifying tube connected in parallel with the input-terminals of the filter network the attainable amplification can be raised only at the cost of the band-width and conversely.

The present invention has for its object to enhance the input-impedance of low or band-pass filters so that when, for instance, it is used as an impedance in the anode circuit of the amplifying tube the product of band-width and amplification is larger than that which could hitherto be attained.

In a circuit arrangement including an impedance constituted by the input-impedance of a low-pass or band-pass filter of the π- or T-type, respectively, whose image-impedance between the input terminals, the nominal value of which amounts to R, corresponds to the image-impedance of the basic type of low or band-pass filters and whose output circuit is terminated by an impedance matched to the image-impedance between the output terminals, according to the invention this purpose is attained by connecting in parallel with the shunt-impedance $2Z_2$ of the π-type lying between the input terminals an impedance

$$\frac{2Z_2}{n}$$

and a negative resistance $-R_1$, respectively, and by connecting in series with the series-impedance $\frac{1}{2}Z_1$ of the T type an impedance $\frac{1}{2}nZ_1$ and a negative resistance $-R_1$, n being given by the expression

$$n=\sqrt{1-\frac{R}{R_1}}$$

The invention will be more clearly understood by reference to the accompanying drawing, given by way of example, wherein Fig. 1 shows a symmetrical low-pass or band-pass filter network of the π-type, embodying the present invention; Fig. 2 shows a known amplifying circuit in the output circuit of which there is included a low-pass filter network of the fundamental π-type; Fig. 3 is a circuit similar to that of Fig. 2, but with the present invention embodied therein; Fig. 4 is a modified form of the invention disclosed in Fig. 3; Fig. 5 shows the application of the invention to a band-pass filter network of the π-type; and Fig. 6 shows a symmetrical low-pass or band-pass filter network of the T-type in accordance with the present invention.

Fig. 1 shows a symmetrical low or band-pass filter network consisting of a series-impedance Z_1 and two shunt-impedances $2Z_2$. It is supposed that the construction of the impedances Z_1 and $2Z_2$ corresponds to that of the fundamental type of the low or band-pass filters or are inferred therefrom by the well-known $m\pi$-transformation. Starting therewith the image-impedance $Z\pi'$, between the input-terminals 1, 2 and, on account of symmetry of the filter network, the corresponding image-impedance be-

tween the output-terminals 3, 4 is given by the expression:

$$Z\pi' = \frac{R}{\sqrt{1-x^2}} \quad (1)$$

In this expression R represents the nominal value of the image-impedance, x in the case of a low-pass filter being given by

$$x = \frac{f}{f_1}$$

where f denotes the frequency and f_1 the limiting frequency, and in the case of a band-pass filter being given by:

$$x = \frac{\frac{f}{f_1 f_2} - \frac{1}{f}}{\frac{1}{f_1} - \frac{1}{f_2}}$$

where f denotes the frequency and f_1 and f_2 represent the lowest and highest limiting frequency respectively.

Between the output terminals of the filter network is connected a resistance R which corresponds to the nominal value of the image-impedance $Z\pi'$.

According to the invention an impedance

$$\frac{2Z_2}{n}$$

and a negative resistance $-R_1$ are connected between the input terminals 1, 2 of the filter network. The impedance Z_i measured between the input-terminals then amounts to

$$Zi = \frac{2Z_2 . R_1 . Z\pi'}{2Z_2 R_1 - 2Z_2 Z\pi' + nZ\pi' R_1} \quad (2)$$

Now it is known from filter-theory that for low and band-pass filters of the fundamental type or filters inferred therefrom according to the $m\pi$ transformation:

$$2Z_2 = \frac{R}{jx} \quad (3)$$

After substitution of the Expressions 1 and 3 in the Expression 2:

$$Z_i = \frac{RR_1}{R_1\sqrt{1-x^2} - R - jnxR_1}$$

The absolute value of the input-impedance Z_i consequently amounts to

$$Zi = \frac{RR_1}{\sqrt{R^2 - 2RR_1\sqrt{1-x^2} + R_1^2(1-x^2) + n^2x^2R_1^2}}$$

The expression $\sqrt{1-x^2}$ forming part of the denominator may be developed in the following series:

$$\sqrt{1-x^2} = 1 - \frac{1}{2}x^2 - \frac{1}{8}x^4 \ldots\ldots$$

so that

$$Z_i = \frac{RR_1}{\sqrt{(R-R_1)^2 + \left(n^2 - 1 + \frac{R}{R_1}\right)x^2R_1^2 + \frac{1}{4}RR_1x^4}}$$

According to the invention n is chosen so as to fulfil the condition:

$$n^2 - 1 + \frac{R}{R_1} = 0 \text{ or } n = \sqrt{1 - \frac{R}{R_1}}$$

hence

$$Z_i = \frac{RR_1}{\sqrt{(R-R_1)^2 + \frac{1}{4}RR_1x^4}} = \frac{R}{n^2\sqrt{1 + \frac{1}{4}\frac{R}{R_1}\frac{x^4}{n^4}}} \quad (4)$$

This expression includes the frequency-dependent magnitude x, i. e. that the absolute value of the input-impedance Z_i is not entirely constant in the transmission band. In practice, however, the deviation makes itself felt only at the edge of the range of transmission.

If, for instance,

$$\frac{R}{R_1} = \frac{1}{3},\ n = \sqrt{\frac{2}{3}}$$

then

$$Z_i = \frac{\frac{3}{2}R}{\sqrt{1 + \frac{3}{16}x^4}}$$

whence it results for a low-pass filter that at the limiting frequency Z_i has fallen to 91.7% of the value at $x=0$ and for $x=0.8$ to 96.3%. Thus, in the Expression 4 above,

$$\frac{1}{4}\frac{R}{R_1}$$

may, to a first approximation, be supposed to be equal to

$$\frac{x^4}{n^4}$$

and very much smaller than 1, hence

$$(Z_i) = \frac{R}{n^2}$$

Since n is smaller than 1 the absolute value of the input-impedance is higher than the input-impedance of the well-known filter referred to above in which the absolute value of the input-impedance amounts to R. Consequently, when the impedance Z_i is used as an anode-impedance of an amplifying tube this circuit permits a larger product of band-width and amplification to be attained than in the case of the known circuit, which will be more fully explained by reference to the circuit arrangements shown in Figures 2 and 3.

Fig. 2 shows the well-known amplifying circuit including an amplifying tube 5 of the pentode-type, whose anode-impedance is constituted by a low-pass filter network of the fundamental π-type consisting of an inductance L_1' in the series branch and a condenser

$$\frac{C_2'}{2}$$

in each shunt branch. The output terminals 3, 4 are terminated by means of a resistance R corresponding to the nominal value of the image impedance

$$Z\pi' = \frac{R}{\sqrt{1-x^2}}$$

a condenser

$$\frac{C_2'}{2}$$

being connected in parallel with the input-terminals 1, 2. From filter theory it follows that

$$C_2' = \frac{1}{\pi f_1 R} (f_1 = \text{limiting frequency})$$

so that

$$\frac{1}{jw\frac{C_2'}{2}} = \frac{R}{jx}$$

Hence we have for the input-impedance Z_i

$$Z_i = \frac{\frac{R}{\sqrt{1-x^2}} \cdot \frac{R}{jx}}{\frac{R}{\sqrt{1-x^2}} + \frac{R}{jx}}$$

whence it follows that $Z_i = R$.

If the mutual conductance of the amplifying tube 5 is S the amplification amounts to $V=S.R$ and since the band-width is given by

$$f_1=\frac{1}{\pi C_2' R}$$

it follows that the product of band-width and amplification is

$$Vf_1=\frac{S}{\pi}\cdot\frac{1}{C_2'}$$

In this case the total capacity between the input terminals of the filter amounts to C_2' and in order to render the product Vf_1 as large as possible this capacity should be made as small as possible, which is the case when this capacity is constituted by the anode-cathode capacity C_{ak} of the amplifying tube 5. In this case:

$$Vf_1=\frac{S}{\pi}\frac{1}{C_{ak}} \quad (5)$$

We shall now consider the amplifying circuit shown in Fig. 3, wherein the anode-impedance of the amplifying tube 5 is an impedance according to the invention. This impedance is constituted by the input-impedance of a low-pass filter similar to that used in the circuit shown in Fig. 2, but now a condenser

$$n\frac{C_2'}{2}$$

and a negative resistance $-R_1$ is connected in parallel with the input terminals 1, 2,

$$n=\sqrt{1-\frac{R}{R_1}}$$

holding good, as has been stated above, for the absolute value of the input impedance

$$Z_1\approx\frac{R}{n^2}$$

and consequently for the amplification

$$V=S\frac{R}{n^2}$$

The band-width amounts to

$$f_1=\frac{1}{\pi C_2' R}$$

so that we eventually have

$$Vf_1=\frac{S}{\pi}\frac{1}{n^2 C_2'} \quad (6)$$

for the product of bandwidth and amplification. The total input capacity of the filter amounts to

$$(n+1)\frac{C_2'}{2}$$

and this is chosen so as to correspond again to the anode-cathode capacity C_{ak} of the amplifying tube, hence

$$(n+1)\frac{C_2'}{2}=C_{ak}$$

or

$$C_2'=\frac{2}{n+1}C_{ak}$$

The latter expression substituted in (6) yields

$$Vf_1=\frac{S}{\pi}\cdot\frac{n+1}{2n^2}\frac{1}{C_{ak}} \quad (7)$$

Upon comparison of the Expressions 5 and 7 it is found that when making use of the circuit shown in Fig. 3 we obtain an improvement of the product of band-width and amplification with respect to the known circuit amounting to a factor

$$\frac{n+1}{2n^2}$$

In the case of

$$n=\frac{1}{3}$$

the improvement amounts to a factor 6.

The negative resistance $-R_1$ may, for instance, be constituted by the internal resistance between anode and cathode of a screen-grid tube, whose anode voltage and screen-grid voltage are adjusted so that the internal resistance is negative. However, this circuit has the drawback that the capacity lying between the input terminals of the filter is increased by the capacity between anode and cathode of the screen-grid tube, which, as appears from what has been said above, results in that the product of band-width and amplification to be attained becomes smaller.

However, the so-called secondary-emission tube is a suitable expedient to secure the negative resistance $-R_1$ without experiencing the drawback just referred to. This is because the internal capacity between cathode and the secondary electron emitting electrode to which the input terminals of the filter are connected is much less than the capacity between cathode and anode of a screen grid tube operating as a negative resistance device. In the latter instance the input terminals of the filter are connected between cathode and anode.

Fig. 4 represents a circuit arrangement comprising a secondary-emission tube. This tube 6 includes a cathode 7, a control-grid 8 to which are supplied the oscillation to be amplified, an auxiliary cathode 9 emitting secondary electrons upon bombardment by electrons and an anode 10. Between the auxiliary cathode 9 and the cathode 7 is connected an impedance constituted by the input impedance of a low-pass filter whose construction corresponds to that of the circuit shown in Fig. 3. According to the invention a condenser

$$n\frac{C_2'}{2}$$

is connected in parallel with the input terminals 1, 2. By a suitable choice of the direct voltage E_h the internal resistance between the auxiliary cathode and the cathode may be adjusted so as to be negative. This negative resistance lies in parallel with the input terminals 1, 2 of the filter and plays the same part as the negative resistance $-R_1$ in the circuit shown in Fig. 3.

Hereinbefore it has throughout been assumed that the impedance between the input terminals of the filter itself, consequently with the omission of the impedance

$$\frac{2Z_2}{n}$$

and the negative resistance $-R_1$ 'n Fig. 1, corresponds to the image impedance Z_π'. Strictly taken this applies only when the output circuit is terminated by the image-impedance Z_π' which, as results from the relation:

$$Z_\pi'=\frac{R}{\sqrt{1-x^2}}$$

depends on the frequency.

The method used in practice to terminate the output circuit by a constant resistance R cor-

responding to the nominal value of the image-impedance gives rise to deviations from the calculated result which in amplifying circuits, for instance, is manifest by falling off of the amplification to a higher degree at the boundaries of the transmission band. However, this drawback can be met in a known manner by arranging for the filter to end with a half section of the m-type which, as is well known, exhibits a more constant characteristic of the image-impedance in the transmission band.

As has already been observed the explanation of the invention given by reference to Fig. 1 also applies for band-pass filters. In the special case of a band-pass filter of the fundamental type the impedance Z_1 in the series-branch consists of the series-connection of an inductance L_1' and a capacity C_1', as more clearly appears from Fig. 5, the shunt-impedances $2Z_2$ being constituted by the parallel-connection of an inductance $2L_2'$ and a condenser

$$\frac{C_2'}{2}$$

According to the invention an impedance

$$\frac{2Z_2}{n}$$

and a resistance $-R_1$ are connected in parallel with the input terminals 1, 2 where

$$n=\sqrt{1-\frac{R}{R_1}}$$

The impedance

$$\frac{2Z_2}{n}$$

consists of an inductance

$$\frac{2L_2'}{n}$$

and a condenser

$$\frac{nC_2'}{2}$$

as appears from Fig. 5. The absolute value of the input impedance Z_i of this band-filter approximately corresponds again to

$$\frac{R}{n^2}$$

Consequently band-pass filters permit the obtainment of the same advantages as those stated by reference to Fig. 3 for a low-pass filter.

In this circuit arrangement, also, it is advisable to connect the resistance R over a half section of the m-type to the output terminals 3, 4.

When using a low-pass filter or a band-pass filter it is not necessary that this should consist of a complete section. The considerations stated above also apply when using a half-section. Furthermore, it is once more observed, that, although in Figures 3 and 5 use is made of a low-pass filter and a band-pass filter of the fundamental type, respectively, the invention is not limited to this kind of filters and that low-pass filters or band-pass filters inferred from the basic type by means of $m\pi$-transformation may be used.

After explaining the invention while making use of filters of the π-type it is superfluous to give an explanation for the case in which the impedance is constituted by the input impedance of a low-pass or band-pass T-filter of the basic type or of a type inferred therefrom by means of well-known mT-transformation. It is sufficient to state that in order to render the absolute value of the input impedance constant an impedance of $\frac{1}{2}nZ_1$ and a resistance $-R_1$ should be connected in series with the input-terminals as illustrated in Fig. 6, $\frac{1}{2}Z_1$ denoting the impedance included in the series-branch of the filter, and n being

$$\sqrt{1-\frac{R}{R_1}}$$

What I claim is:

1. An amplifier circuit comprising an electron discharge tube one of the circuits of which includes an impedance constituted by the input-impedance of a filter of the π-type, whose image impedance between the input-terminals, the nominal value of which amounts to R, corresponds to the image impedance of the basic type of filter and whose output circuit is terminated by an impedance matched to the image impedance between the output terminals, in which in parallel with the shunt impedance $2Z_2$ of the π-type lying between the input-terminals are connected an impedance

$$\frac{2Z_2}{n}$$

and a negative resistance $-R_1$, n being given by the expression:

$$n=\sqrt{1-\frac{R}{R_1}}$$

2. An amplifier circuit according to the invention defined in claim 1, wherein the electron discharge tube includes an electrode which emits secondary electrons, and the input terminals of the filter are connected, respectively, to said secondary electron emitting electrode and to the tube cathode, and the negative resistance is constituted by the internal resistance between said electrode and cathode.

3. An amplifier circuit comprising an electron discharge tube one of the circuits of which includes an impedance constituted by the input-impedance of a filter of the T-type, whose image impedance between the input-terminals, the nominal value of which amounts to R, corresponds to the image impedance of the basic type of filter and whose output circuit is terminated by an impedance matched to the image impedance between the output terminals, and in which in series with the series-impedance $\frac{1}{2}Z_1$ of the T-type are connected an impedance $\frac{1}{2}nZ_1$ and a negative resistance $-R_1$, n being given by the expression:

$$n=\sqrt{1-\frac{R}{R_1}}$$

4. An amplifying circuit arrangement comprising an impedance constituted by the input impedance of a standard derived type of filter whose image impedance between the input terminals has the nominal value R which is equal to the image impedance of the corresponding basic type of filter and whose output circuit is terminated by an impedance matched to the image impedance between the output terminals, said circuit arrangement having a negative resistance element connected to the initial reactance element of said filter to produce therewith a composite impedance network having a negative power factor, that is, a negative ratio of real component to magnitude of imaginary component, determined by the ratio of the impedances

of said elements, and wherein the magnitude of the impedance of said initial element is so altered as to reduce the magnitude of said power factor by the factor

$$\frac{1}{n+1}$$

the value of n being given by the expression

$$\sqrt{1-\frac{R}{R_1}}$$

where R_1 is the magnitude of said negative resistance.

5. An impedance network adapted to provide an increased product of impedance and band width of frequencies over which said impedance is substantially constant in magnitude, comprising the input terminals of a mid-section terminated derived type filter whose output terminals are closed upon a terminating resistance of such magnitude as to produce a substantially non-reflective termination, a negative resistance connected to the initial reactance element of said filter whereby to produce therewith a composite element having a negative power factor, and further reactance connected to said initial reactance element and so chosen as to alter solely the magnitude of said initial reactance at every frequency, said alteration of magnitude being of such amount as to cause the power factor of the so altered composite element to be reduced to

$$\frac{1}{n+1}$$

times the first mentioned power factor, where

$$n=\sqrt{1-\frac{R}{R_1}}$$

R being the magnitude of said terminating resistance and R_1 being the magnitude of said negative resistance.

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