Feb. 16, 1937. A. J. GROSSMAN 2,070,656

FREQUENCY SELECTIVE TRANSMISSION CIRCUIT

Filed Nov. 27, 1934

FIG. 1

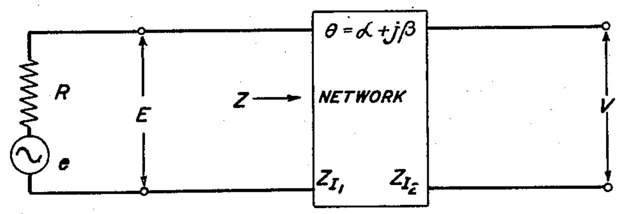


FIG. 2

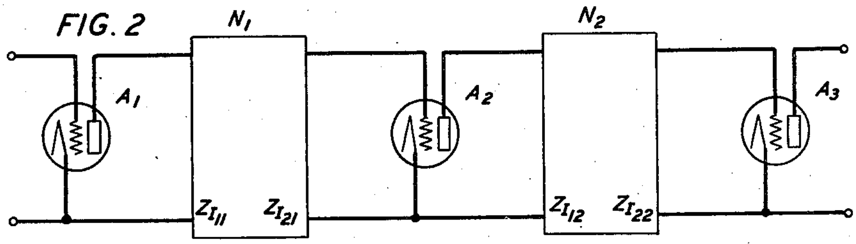


FIG. 3

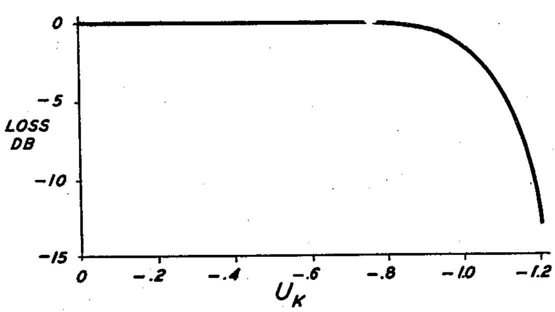


FIG. 3A

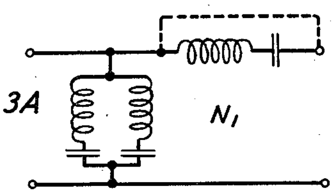


FIG. 3B

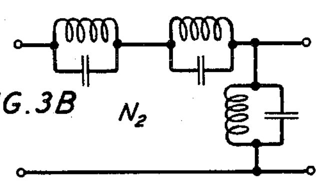


FIG. 4

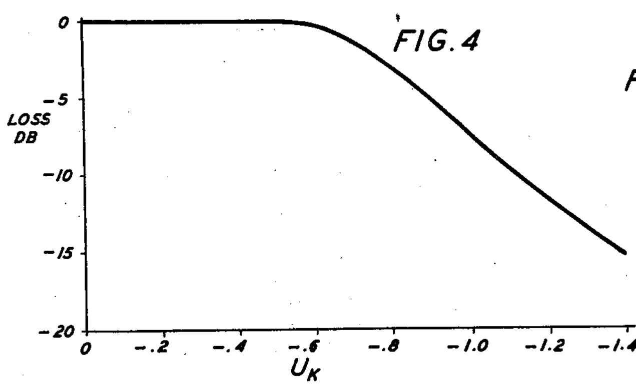


FIG. 4A

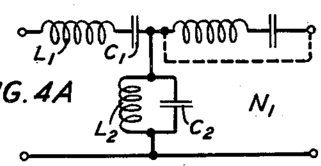
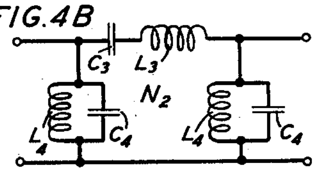


FIG. 4B



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UNITED STATES PATENT OFFICE

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FREQUENCY-SELECTIVE TRANSMISSION CIRCUIT

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Application November 27, 1934, Serial No. 754,933

3 Claims. (Cl. 178—44)

The present invention relates to amplifiers having a flat characteristic over a desired frequency range, and where desired, a high degree of selectivity between transmitted and suppressed frequency ranges.

The invention provides an improved manner of constructing multi-stage amplifier circuits which will give high quality amplification at high gain.

In accordance with the invention the interstage circuits of a multi-stage amplifier are networks of the same or different construction from stage to stage to secure an overall desired amplifier characteristic. In particular these networks may comprise filters or filter sections which in two successive interstage positions have inversely related characteristic impedances at all frequencies thus avoiding the possibility of self-oscillation of the stage with which they are associated. Moreover, these networks have voltage transmission characteristics which may differ from one another but which add together to form a desired resultant over the transmitted frequency range. By terminating these networks open-circuit on their output sides full advantage is taken of their voltage amplifying properties, this being practicable in view of the high input impedance of space discharge type amplifiers such as ordinary three-element tubes or more especially tubes having more than a single grid element. In a preferred form, the successive interstage filter networks exhibit output image impedance characteristics, the product of which is equal or proportional to the product of the output impedances of the tubes, their input image impedances being approximately matched to the tube output impedances to which their inputs are respectively connected.

A better understanding of the invention and of its various objects and features will be had from the following detailed description taken in connection with the drawing in which:

Fig. 1 is a simple circuit diagram to be referred to in the derivation of certain mathematical expressions;

Fig. 2 is a schematic diagram of a multi-stage amplifier of the invention including interstage networks;

Figs. 3, 3A and 3B relate to one type of network and network characteristic applicable to the circuit of Fig. 2; and

Figs. 4, 4A and 4B relate to another type of network and network characteristic that may be used.

Referring to the generalized circuit diagram of Fig. 1, the transmission properties of the network will be defined in terms of the ratio of the output voltage V to the generator voltage *e*. When

$$\left[\frac{V}{e}\right]=1$$

there exists free transmission and when

$$\left[\frac{V}{e}\right]=0$$

there exists infinite attenuation. Symbols are used as follows:

Z_{I_1}=input image impedance;
Z_{I_2}=output image impedance;
R is the generator impedance; and
θ is the transfer constant.

In Fig. 1,

$$\frac{E}{e}=\frac{Z}{R+Z}$$

The input impedance of an open-circuited network is known to be:

$$Z=Z_{I_1}\coth\theta$$

Hence:

$$\frac{E}{e}=\frac{1}{1+\frac{R}{Z_{I_1}}\tanh\theta} \qquad (1)$$

It is known from considering the equivalent "T" of a general four-terminal network that:

$$\frac{V}{E}=\sqrt{\frac{Z_{I_2}}{Z_{I_1}}}\cdot\frac{1}{\cosh\theta} \qquad (2)$$

combining (1) and (2) gives:

$$\frac{V}{e}=\sqrt{\frac{Z_{I_2}}{Z_{I_1}}}\left[\frac{1}{\cosh\theta+\frac{R\sinh\theta}{Z_{I_1}}}\right] \qquad (3)$$

which completely describes the transmission properties of the Fig. 1 circuit.

In Fig. 2 three amplifier stages are shown comprising amplifier stages A_1, A_2 and A_3 intercoupled with networks N_1 and N_2. Any suitable input and output circuits may be assumed for stages

A_1 and A_3 respectively. If it is assumed that networks N_1 and N_2 are inverse to each other, and that θ is the image transfer constant of each, the following relations may be set down:

$$Z_{I_{11}}Z_{I_{12}}=K_1^2=R_1R_2$$

$$Z_{I_{21}}Z_{I_{22}}=K_2^2$$

$Z_{I_{11}}$=input image impedance of N_1

$Z_{I_{21}}$=output image impedance of N_1

$Z_{I_{12}}$=input image impedance of N_2

$Z_{I_{22}}$=output image impedance of N_2

R_1=the "generator" impedance of A_1

R_2=the "generator" impedance of A_2

Let

$\left(\frac{V}{e}\right)_1$=the voltage transmission from the internal generator of tube A_1 to the grid of tube A_2, and

Let

$\left(\frac{V}{e}\right)_2$=the voltage transmission from the internal generator of tube A_2 to the grid of tube A_3.

Then from Equation (3):

$$\left(\frac{V}{e}\right)_1\cdot\left(\frac{V}{e}\right)_2=\frac{V}{e}=\frac{K_2}{\sqrt{R_1R_2}}\cdot\left[\frac{1}{\cosh\theta+\frac{R_1}{Z_{I_{11}}}\sinh\theta}\right]\cdot\left[\frac{1}{\cosh\theta+\frac{R_2}{Z_{I_{12}}}\sinh\theta}\right]$$

$$\frac{V}{e}=\frac{K_2}{\sqrt{R_1R_2}}\,\frac{1}{\cosh 2\theta+\left[\frac{R_1}{Z_{I_{11}}}+\frac{Z_{I_{11}}}{R_1}\right]\frac{\sinh 2\theta}{2}}$$

or

$$\frac{V}{e}=\frac{K_2}{\sqrt{R_1R_2}}\,\frac{1}{\cosh 2\theta+\left[\frac{R_2}{Z_{I_{12}}}+\frac{Z_{I_{12}}}{R_2}\right]\frac{\sinh 2\theta}{2}}$$

From this it appears that if

$$\left[\frac{R_1}{Z_{I_{11}}}+\frac{Z_{I_{11}}}{R_1}\right]\doteq 2$$

that is, if

$$\frac{R_1}{Z_{I_{11}}}\doteq 1$$

$$\frac{V}{e}=\frac{K_2}{\sqrt{R_1R_2}}\times\frac{1}{e^{2\theta}}$$

Since in the theoretical transmitting band of the network the real part of θ is zero, then

$$\left[\frac{V}{e}\right]\doteq\frac{K_2}{\sqrt{R_1R_2}}$$

which is a constant indicating uniform or flat transmission in the theoretical transmitting band of the network.

If

$$\frac{K_2}{\sqrt{R_1R_2}}$$

is made equal to unity, free transmission is obtained.

The approach to unity of the quantity

$$\frac{R_1}{Z_{I_{11}}}$$

need not be close. In fact if the value of this expression lies between

$$\frac{1}{1.5}$$

and 1.5, very good results in flat transmission are obtained.

Examples of two types of networks are given in the drawing. Figs. 3A and 3B show one general type of network, the m-derived half-section filter type (with the parameter m=.6), the network N_1 (referred to in Fig. 2) being shown schematically in Fig. 3A and the network N_2 in Fig. 3B, or vice versa. The calculated loss-frequency curve for this combination of networks used as in Fig. 2 is given in Fig. 3 in terms of the quantity U_K where this is equal to

$$U_K=\frac{-\left[\frac{f}{f_m}-\frac{f_m}{f}\right]^2}{\left[\frac{f_2}{f_m}-\frac{f_m}{f_2}\right]^2}$$

f, f_m and f_2 being respectively any frequency (the variable), the geometric mean of the theoretical cut-off frequencies and the theoretical upper cut-off frequency.

It is apparent from Fig. 3 that the transmission is flat, out to U_K=.9, with sharp cut-off at the band edges. In this figure, it will be understood that the whole band is symmetrical about the point U_K=0.

A type of network giving less sharpness of cut-off is shown in Figs. 4A and 4B (for networks N_1 and N_2 respectively (or vice versa) of Fig. 2). The calculated loss-frequency characteristic is given in Fig. 4.

In an actual circuit incorporating the Figs. 4A, 4B type of network in the general circuit of Fig. 2, the following values were used. Tubes A_1 and A_2 were Western Electric No. 101D type and tube A_3 was 102D type. L_1 was a 66.5 millihenry inductance; L_2 was a 3.47 millihenry inductance, C_1 was a .000238 microfarad condenser; and C_2 was a .00456 microfarad condenser. The dotted line in Fig. 4A means that the series inductance and capacity on the output side were omitted, this being permissible since the filter worked into a half megohm grid resistor. In general under such circumstances the output series elements of the network may be omitted as is also indicated in Fig. 3A.

In N_2, C_3 was a .000119 microfarad condenser, C_4 was a .002280 microfarad condenser, L_3 was a 133 millihenry inductance and L_4 was a 6.94 millihenry inductance. The L_1C_1 and L_3C_3 combinations were each resonant at 40 kilocycles and the L_2C_2 and L_4C_4 combinations were anti-resonant at that frequency. The band cut-offs were at 35.22 and 45.32 kilocycles.

Many types of networks can be used which will satisfy the conditions given above, that is, whose input image impedances are approximately equal to the generator impedances over the frequency range of interest and which are designed to operate into substantially open-circuit impedance. By operating on open-circuit on their output side, advantage is taken of a six decibel voltage gain as compared with operating into a load impedance equal to the output impedance.

One example of a suitable type network would be a constant resistance equalizer of either the bridged-T or lattice form. Use could be made of the general lattice type filter disclosed in United States patent to Bode, No. 1,828,454, dated October 20, 1931. Other types will suggest themselves in relation to specific requirements in given cases.

While three-element tubes have been shown in Fig. 2, any suitable type of tube may be used and it will be advantageous to use tubes of high input impedance such as screen grid tubes, pentodes, or tubes whose input capacity is small. Any suitable number of amplifier stages may be used, the three stages shown being by way of example. If a large number of stages is used, the idea of using networks whose image impedances are the inverse of each other can be extended to other stages in the general manner indicated.

What is claimed is:

1. An amplifier comprising tandem stages coupled by respective four-terminal networks having desired frequency band transmission characteristics, said networks having input image impedances whose product approximately matches the product of the amplifier output impedances out of which they work and having output image impedances terminating open-circuit, the product of said output image impedances being a constant and proportional to the product of said amplifier impedances which is also a constant.

2. An amplifier comprising tandem stages coupled by respective four-terminal interstage networks which cooperate to give the amplifier a desired frequency-amplitude characteristic, said networks having input image impedances whose product substantially matches the product of the amplifier output impedances out of which they work and being terminated on their output sides in substantially open-circuit impedances.

3. In a multi-stage amplifier, a succession of amplifier elements, impedance networks each connecting the output of one amplifier element to the input of the next amplifier element, said networks each having input image impedances approximately equal to the amplifier element output impedances to which their inputs are connected, and being terminated at their output sides in substantially open-circuit impedances, the product of the output image impedances of said networks being substantially a constant independent of frequency throughout a range of frequencies to be amplified.

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