Nov. 12, 1940. W. SIX 2,221,116

DEGENERATIVE AMPLIFIER CIRCUIT

Filed April 19, 1933

Fig. 1

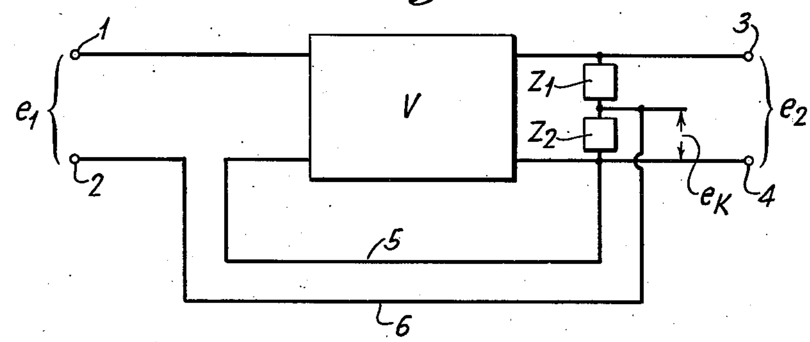


Fig. 2

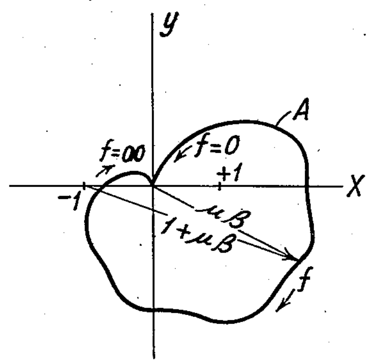


Fig. 3

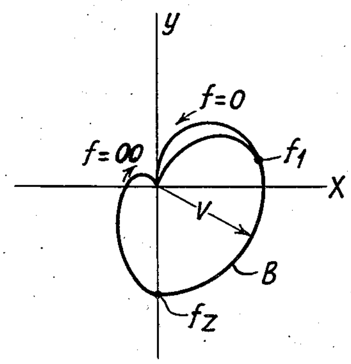
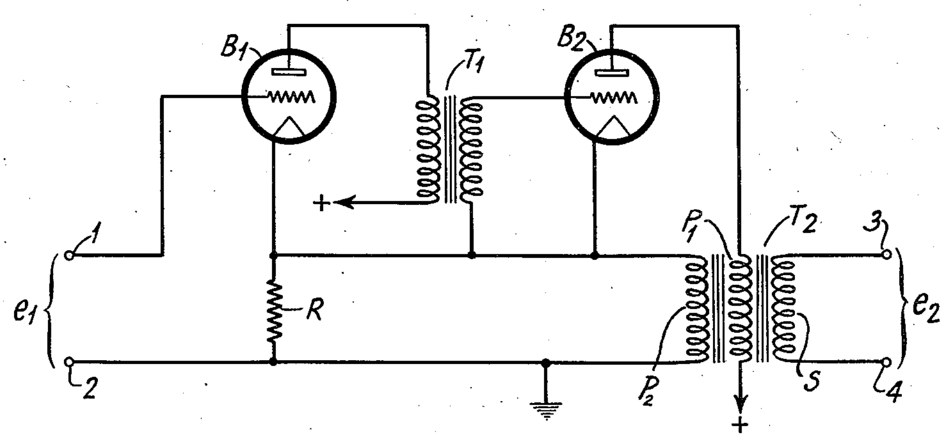


Fig. 4



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DEGENERATIVE AMPLIFIER CIRCUIT

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4 Claims. (Cl. 179—171)

This invention relates to amplifiers provided with degenerative back-coupling in order to decrease the non-linear deformation occurring in the amplifier.

As is well-known in such amplifying arrangements a voltage is taken off from the anode circuit of an amplifying tube, which voltage is supplied back through a back-coupling circuit to the grid circuit of the same tube, or of a preceding amplifying tube. In the optimum case the phase difference between this voltage and the voltage to be amplified which is immediately supplied to the grid circuit amounts to 180°. Under certain conditions, however, positive back-coupling instead of degenerative back-coupling may occur, by which positive back-coupling the amplifier may be caused to oscillate, which will be explained with reference to Figs. 1 and 2 of the accompanying drawing.

In the drawing:

Fig. 1 shows schematically a negative feedback circuit for the purpose of analysis,

Fig. 2 is a graphic analysis of the action of the feedback circuit of Fig. 1,

Fig. 3 is a graphic analysis of the problem sought to be solved by this invention,

Fig. 4 illustrates a circuit embodying the invention.

Fig. 1 represents an amplifier V comprising input terminals 1 and 2, to which is supplied the voltage e_1 to be amplified, and output terminals 3 and 4 between which occurs the amplified voltage e_2. By means of a potentiometer consisting, for instance, of two impedances Z_1 and Z_2 a voltage $e_k=\beta e_2$ is taken off from the output circuit of the amplifier and supplied back through the connecting lines 5 and 6 to the input circuit of the amplifier. When the amplification of the amplifier without back-coupling is μ, the amplification μ' with back-coupling is given by the relation:

$$\mu'=\frac{e_2}{e_1}=\frac{\mu}{1+\mu\beta}$$

Generally μ, μ' and β and consequently also the product $\mu\beta$ are complex values which are dependent on the frequency and may be represented by vectors. The locus of the end point of the vector $\mu\beta$ for all frequencies between 0 and ∞ will then be given, for instance, by the curve A shown in Fig. 2, which is so constructed that the horizontal coordinate measured on the X-axis and the perpendicular coordinate measured on the Y-axis of any point of the curve respectively correspond to the real and imaginary part of the complex value $\mu\beta$ respectively. It further follows that the complex value $1+\mu\beta$ for any frequency is given by the vectors drawn from the point on the horizontal axis with the coordinate -1 to the periphery of the curve A.

Nyquist (see Bell System Technical Journal, Jan. 1932, pages 126–147) has shown that the amplifier will not oscillate at any frequency if the curve A does not include the point -1 on the horizontal axis. In other words the point -1 should not lie inside the plane enclosed by the curve A. Now this condition is not satisfied when in the amplifier two transformers are connected between the points from which is derived the voltage back-coupled in a degenerative manner and the points to which this voltage is supplied back. To explain this more clearly the ratio between the secondary voltage and the primary voltage of a transformer for all frequencies between 0 and ∞ (this ratio may be represented by a complex value v) is represented by the curve B of Fig. 3 which similarly to the curve A shown in Fig. 2 is constructed so that the coordinates of any point of the curve measured on the X- and the Y-axis indicate the real and imaginary part respectively of the ratio v.

Transformers used in amplifiers are proportioned so that the absolute value of the voltage ratio v in the range of frequencies to be uniformly amplified is about constant. In Fig. 3 the lowest frequency of this range is represented by f_1 and the highest frequency coinciding with the leakage resonance frequency of the transformer by f_2. Consequently the length of the vector v is substantially constant between these limits, whereas for the frequencies higher than f_2 the length of v rapidly decreases. Furthermore, it appears from Fig. 3 that the phase displacement between the primary and the secondary voltage amounts to 90° at the leakage resonance frequency.

In view of this behavior of a transformer it will be appreciated that self-oscillation of the amplifier with sufficient degenerative back-coupling is unavoidable when the amplifier part equipped with degenerative back-coupling includes two transformers calculated about for the same frequency band, such as is the case in the amplifier represented in Fig. 4. At the leakage resonance frequency the total phase displacement caused by the two transformers amounts already to 180°, whereas this frequency lies in the range of uniform amplification, in which μ and β have such values in practice that $\mu\beta>1$. Under these conditions the point -1 lies inside the plane enclosed by the curve A in Fig. 2 so that the amplifier will oscillate.

In Fig. 4 the amplifier B_1 has the input voltage e_1 applied between input terminals 1 and 2. The transformer T_1 couples the plate circuit of B_1 to the input electrodes of the following amplifier B_2. Transformer T_2 is schematically represented, but it is to be understood as comprising a split primary winding. One section P_1 of the primary has its upper end connected to the plate of amplifier B_2, while its lower end is connected to the positive terminal of the direct current source (not shown). The second primary section P_2 has one end connected to the grounded end of the current source, while the opposite end thereof is connected to the cathode leads of tubes B_1 and B_2. Resistor R connects the cathode of amplifier B_1 to ground. It will be noted that the secondary winding S feeds the output voltage e_2 to terminals 3 and 4. The direct current source, it will be seen, is in series relation between the primary sections P_1 and P_2. The alternating voltage across winding P_2 is impressed between the input electrodes of B_1. The problem is to accomplish the degenerative feedback without oscillation production.

This difficulty is obviated when, according to the invention, the leakage resonance frequency of one of the two transformers T_1 and T_2 exceeds the leakage resonance frequency of the other transformer and the range of frequencies to be amplified is limited by the lowest leakage resonance frequency. In this case the total phase displacement caused by the two transformers in the range of frequencies to be amplified is less then 180° and since the voltage transmission of the transformer with a low leakage resonance frequency rapidly decreases for frequencies exceeding the leakage resonance, the absolute value of $1+\mu\beta$ will also rapidly decrease for these frequencies. In this manner it is possible by a suitable choice of the leakage resonance frequencies to give the curve A in Fig. 2 traced by the vector $1+\mu\beta$ such a shape that the point -1 is not enclosed by the curve, so that the amplifier cannot oscillate.

What is claimed is:

1. In an amplifier for uniformly amplifying alternating voltage of a range of frequencies, voltage input terminals and output terminals, said amplifier comprising a pair of cascaded tubes, the first of the tubes having its input electrodes connected to said input terminals, a transformer coupling the output electrodes of the first tube to the input electrodes of the second tube, a second transformer coupling the second tube output electrodes to said output terminals, said second transformer including a section thereof coupled to said first tube input electrodes to feed back voltage in degenerative phase, said transformers having leakage resonance frequencies which are sufficiently different to prevent said feed back causing oscillation.

2. In an amplifier for uniformly amplifying alternating voltage of a range of frequencies, voltage input terminals and output terminals, said amplifier comprising a pair of cascaded tubes, the first of the tubes having its input electrodes connected to said input terminals, a transformer coupling the output electrodes of the first tube to the input electrodes of the second tube, a second transformer coupling the second tube output electrodes to said output terminals, said second transformer including a section thereof coupled to said first tube input electrodes to feed back voltage in degenerative phase, said transformers having leakage resonance frequencies which are sufficiently different to prevent said feed back causing oscillation, one of said transformers having its said leakage resonance frequency located substantially beyond the highest frequency of said frequency range.

3. In an amplifier for uniformly amplifying alternating voltage of a range of frequencies, voltage input terminals and output terminals, said amplifier comprising a pair of cascaded tubes, the first of the tubes having its input electrodes connected to said input terminals, a transformer coupling the output electrodes of the first tube to the input electrodes of the second tube, a second transformer coupling the second tube output electrodes to said output terminals, said second transformer including a section thereof coupled to said first tube input electrodes to feed back voltage in degenerative phase, said transformers having leakage resonance frequencies which are sufficiently different to prevent said feed back causing oscillation both said leakage resonance frequencies being located at the upper end of said frequency range, and the lower of the leakage frequencies limiting said range.

4. In an alternating voltage amplifier network of the type including at least two electron discharge tubes coupled in cascade by a transformer, an output transformer coupled to the second tube output electrodes, and a degenerative voltage feedback connection between said output transformer and the input electrodes of the first tube; the improvement which comprises said coupling and output transformers having sufficiently different leakage resonance frequencies to prevent the production of oscillations in said amplifier.

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