Dec. 16, 1941. K. POSTHUMUS 2,266,073

SYSTEM FOR AMPLIFYING MODULATED WAVES

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Fig. 1.

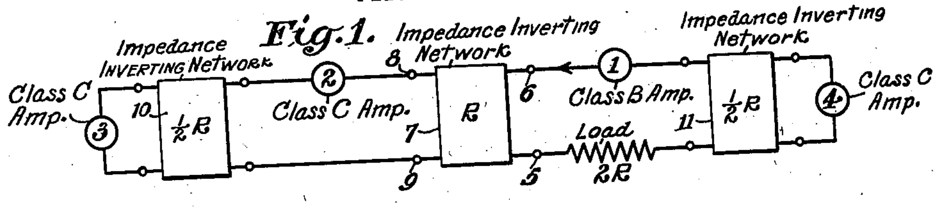

Fig. 2.

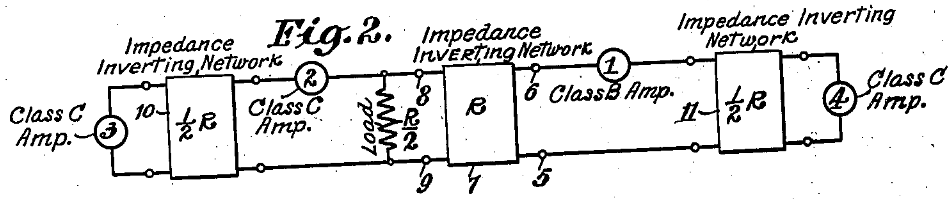

Fig. 3.

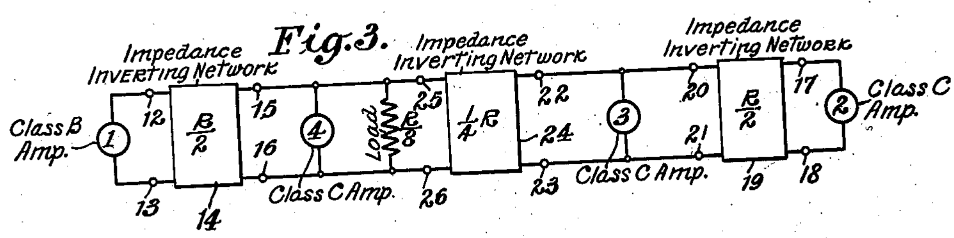

Fig. 4.

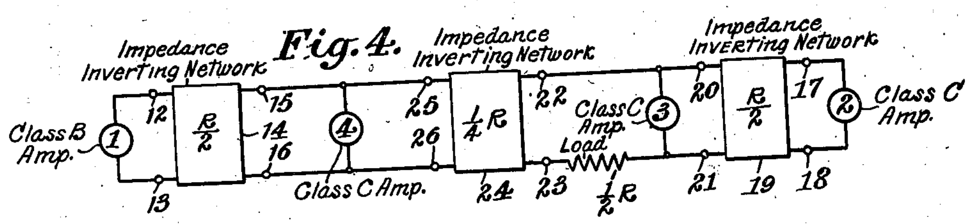

Fig. 6.

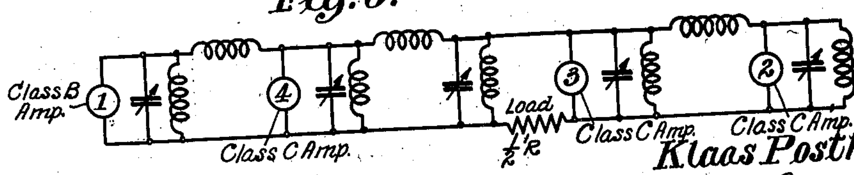

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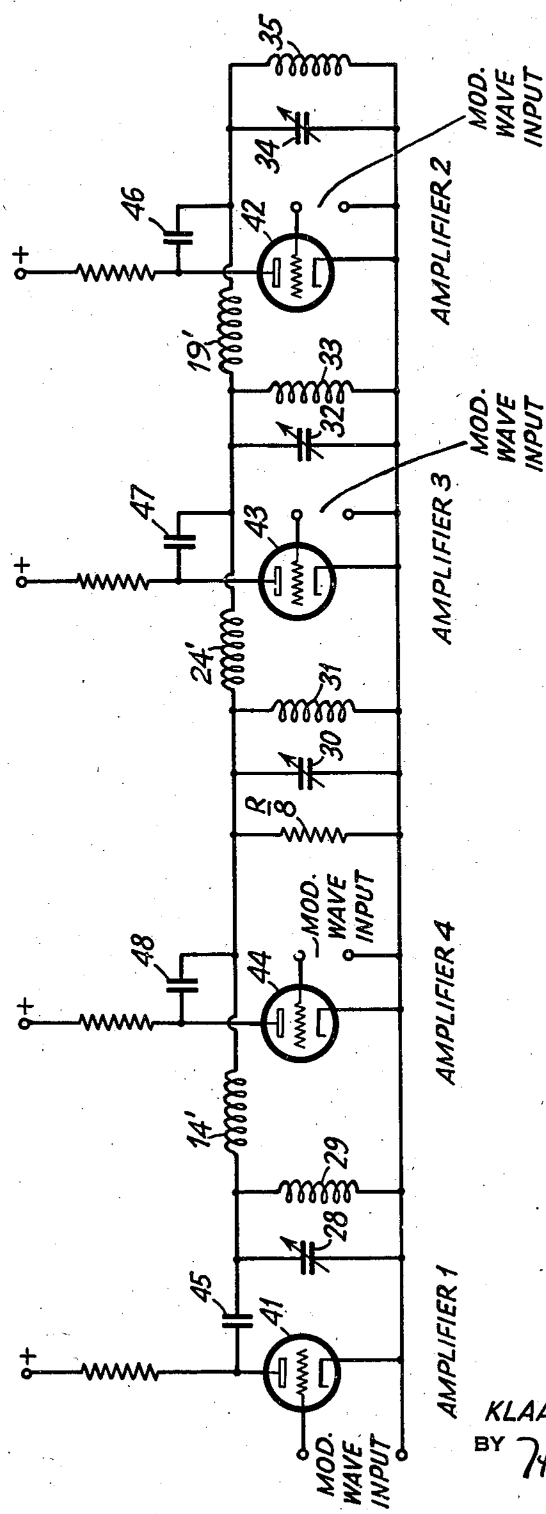
Fig. 5



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SYSTEM FOR AMPLIFYING MODULATED WAVES

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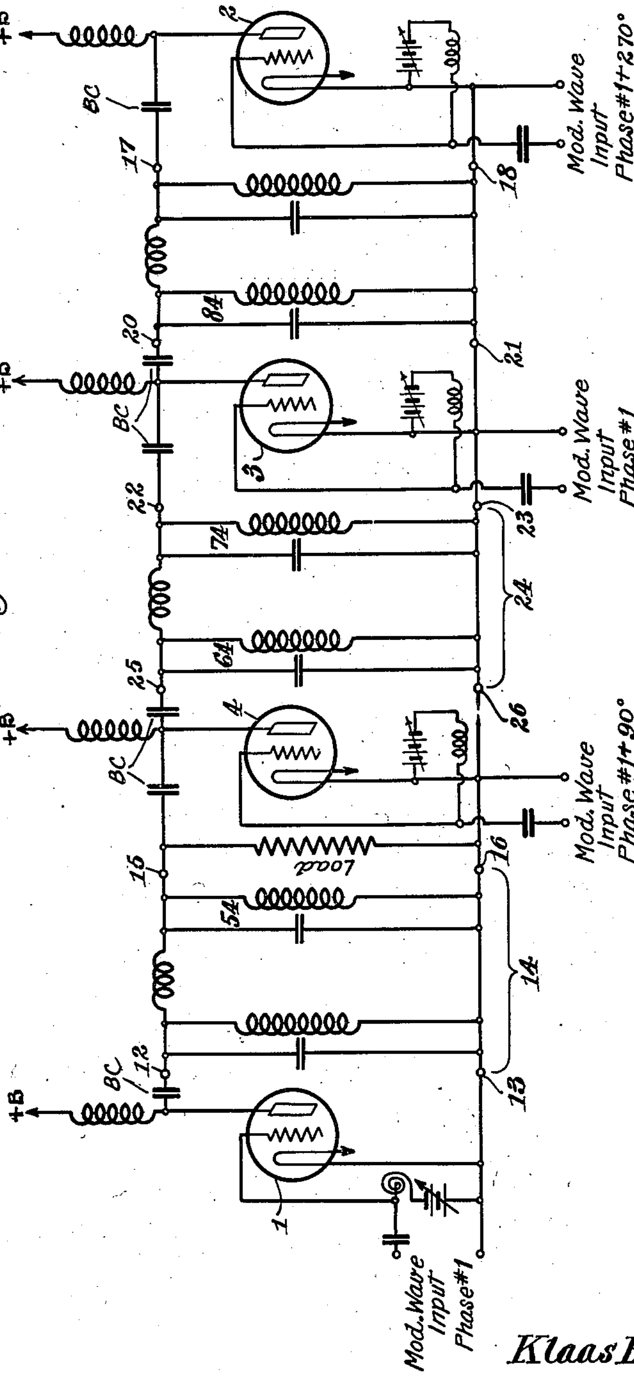
Fig. 7.



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UNITED STATES PATENT OFFICE

2,266,073

SYSTEM FOR AMPLIFYING MODULATED WAVES

Klaas Posthumus, Eindhoven, Netherlands, assignor to Radio Corporation of America, New York, N. Y.

Application January 5, 1940, Serial No. 312,576
In the Netherlands November 10, 1938

8 Claims. (Cl. 179—171)

This invention relates to a system for amplifying modulated oscillations, which is particularly suitable for the final stage of a transmitter modulated in a preceding stage. The arrangement of the system may also be such that the modulation takes place in the final stage itself.

In order to improve the efficiency of the final stage of a transmitter, it has previously been proposed to compose the amplifier of a combination of a class B and a class C amplifier. With an unmodulated carrier-wave amplitude the class B amplifier is fully loaded, so that the alternating voltage set up by this amplifier can no longer increase; but the current may still grow. When the instantaneous value of the modulated carrier wave increases so as to exceed the unmodulated carrier wave amplitude, the class C amplifier starts operating and supplies energy to a common load impedance. Between the class B or the class C amplifier and the common load impedance is connected a so-called impedance inverting network which possesses the property that the impedance occurring between the input terminals is inversely proportional to the impedance connected between the output terminals, and inversely.

Applicant proposed in United States application #168,155, filed October 9, 1937, now Patent No. 2,230,122, January 28, 1941, to utilize a class B amplifier and three class C amplifiers, which are connected in a suitable manner through the intermediary of impedance inverting networks to a common load impedance. The circuit arrangement is such, that with an instantaneous value of the high-frequency amplitude which is lower than the unmodulated carrier wave amplitude, the class B amplifier is fully loaded. At this instantaneous value one of the class C amplifiers starts operating owing to the fact that this amplifier has a threshold value which is equal to the said instantaneous value of the carrier wave amplitude. These conditions are maintained until at a sufficiently large modulation depth, the instantaneous value of the high-frequency amplitude surpasses the threshold value of the two other class C amplifiers, whose threshold values are mutually equal, whereupon the class C amplifiers also supply energy to the load impedance. With a 100% modulation depth all the amplifiers supply in this case the same amount of energy to the load impedance.

In describing my invention, reference will be made to the attached drawings, wherein Figures 1 and 2 show diagrammatically efficient amplifying systems of the type involved here and such as disclosed in my said prior application. These figures are used herein to explain the nature of the systems involved and the object of my invention which is to provide improved amplifiers of this type; Figures 3 and 4 show diagrammatically amplifying systems of the present invention comprising several stages and their couplings and the coupling of the amplifier to a load impedance; Figures 5 and 7 illustrate somewhat in greater detail efficient amplifying systems of the nature shown diagrammatically in Fig. 3; while Figure 6 illustrates in somewhat greater detail an efficient amplifying system of the nature shown diagrammatically in Figure 4 of the drawings.

Figure 1 of the drawings represents the system described in the prior application. In this Figure 1 denotes a class B amplifier which is loaded with a resistance 2R. In the output circuit of the class B amplifier are located the terminals 5 and 6 of an impedance inverting network 7 whilst to the input terminals is connected a class C amplifier 2 whose threshold value is chosen by means of the bias voltage in such manner, that this amplifier passes current only if the instantaneous value of the amplitude of the oscillations to be amplified surpasses a predetermined value which is smaller than the unmodulated carrier wave amplitude. In the circuit which comprises the amplifier 1, the load value 2R and the terminals 5 and 6 is included the output impedance of an impedance inverting network 11 which has connected to its input terminals a class C amplifier 4 whose threshold value is chosen by means of the bias voltage in such manner, that the amplifier only passes current if the instantaneous value of the amplitude of the oscillations to be amplified surpasses a pre-determined value which is greater than the unmodulated carrier wave amplitude. In the circuit which comprises the amplifier 2 and the terminals 8 and 9 of the network 7 is included the output impedance of an impedance network 10 which has connected to its input terminals a class C amplifier 3 whose threshold value has the same value as the class C amplifier 4. The networks 7, 10 and 11 are called "impedance inverting" because they possess the property that the input impedance is inversely proportional to the impedance connected between the output terminals, said property being reversible. The surge impedance R_0 of the network 7 is R while those of the networks 10 and 11 amount to $R/2$. Since each of the networks 7, 10 and 11 brings about a phase-displacement of 90°, the high-frequency alternating voltages supplied to the input circuits of the class C amplifiers 2, 3, and 4 are displaced in phase by 90°, 180°, and 90° respectively, with respect to the voltage supplied to the class B amplifier 1.

If an unmodulated carrier oscillation is supplied to the amplifiers, the class B amplifier 1 is operative during the whole cycle and the class C amplifier 2 during only part of the cycle. During that part of the cycle in which the class C amplifier 2 is not conductive, the amplifier 1 is loaded with a resistance 2R. At the moment when the class C amplifier 2 begins to supply energy, the instantaneous value of the voltage set up in the output circuit of the class B amplifier 1 has attained its highest admissible value so that at this moment the amplifier 1 operates with maximum efficiency. During that part of the cycle in which the class C amplifier 2 supplies energy, the load resistance of the class B amplifier 1 is smaller than 2R, owing to which an increase of the anode current of the amplifying tubes becomes possible without any increase of the anode alternating voltage.

At the moment when the C amplifiers 3 and 4 begin to supply energy, the anode alternating voltage of the class C amplifier 2 has attained its highest permissible value and the load resistance of the class B amplifier 1 is equal to R whilst the load resistance of the class C amplifier 2 also amounts to R. At this moment the amounts of energy furnished by each of the two amplifiers 1 and 2 are equal. When the instantaneous value of the oscillations to be amplified surpasses the threshold value of the class C amplifiers 3 and 4, the load of the amplifiers 1 and 2 decreases. At the maximum voltage of the 100% modulated carrier oscillation the amplifiers 3 and 4 are fully loaded with the result that the load resistance of the amplifiers 1 and 2 has decreased from the value R to the value ½R. Owing to an increase of the anode currents of the amplifiers 1 and 2 the output energy of these amplifiers has increased to double the value obtained at the moment when the threshold value of the amplifiers 3 and 4 is surpassed. At the maximum voltage of a 100% modulated carrier oscillation the amplifiers 3 and 4 are each loaded with a resistance

$$\frac{R_0^2}{R/2}=\frac{1}{2}R$$

since the surge impedance R_0 of the networks 10 and 11 amounts to $R/2$. At this moment each of the amplifiers 1, 2, 3, and 4 delivers an equal amount of energy and the efficiency of the whole of the installation is equal to the maximum efficiency of a class B amplifier which furnishes the same output energy.

Figure 2 represents another system according to the prior application which is completely dual to the system according to Figure 1 and which operates in a similar manner. In this system the class B amplifier 1 is connected to a load impedance $R/2$ through the intermediary of an impedance inverting network 7 which possesses the same property as the network 7 in the system of Fig. 1. The class C amplifier 2 is connected to the ends of this impedance. The surge impedance of the filter 7 amounts to R. In the circuit which comprises the class B amplifier 1 and the terminals 8 and 9 of the network 7 is included the output impedance of an impedance inverting network 11 whose surge impedance amounts to $R/2$ and to the input terminals of which is connected the class C amplifier 4. In the circuit which comprises the class C amplifier 2 and the load resistance $R/2$ is included the output impedance of an impedance inverting network 10 whose impedance amounts to $R/2$ and whose input terminals have a class C amplifier 3 connected to them. The bias voltages and the mutual phase displacements of the oscillations supplied to the input circuits of the amplifiers 1, 2, 3 and 4 are the same as in the system according to Fig. 1. Also, the variation of the load resistances of the different amplifiers as a function of the modulation is exactly similar to that occurring in the previously described circuit arrangement.

It will be evident that when two of the amplifiers in Figures 1 and 2 are earthed the two other amplifiers cannot be earthed unless they are inductively coupled with the circuit in which the load impedance is included.

The present invention relates to a system which comprises, as does the above-described system, four amplifiers which successively supply, at different values of the high-frequency amplitude, energy to a common load impedance and wherein all amplifiers can be earthed without the use of inductive coupling.

According to the invention, the class B amplifier 1 is connected to the input terminals of an impedance inverting network to the output terminals of which is connected one of the class C amplifiers with a high threshold value 4, whilst the class C amplifier with the lowest threshold value 2 is connected to the input terminals of an impedance inverting network to the output terminals of which is connected the other class C amplifier of high threshold value 3, the latter amplifier being connected either through the intermediary of the impedance inverting network to a load impedance connected in parallel with the other class C amplifier of high threshold value 4 or through a load impedance to the output terminals of an impedance inverting network to the input terminals of which is connected the other class C amplifier of high threshold value 4 whilst the surge impedance of the two first-mentioned networks amounts to double the surge impedance of the last-mentioned network and is equal to the load impedance or four times as large as this impedance respectively and wherein the various amplifiers are supplied with a phase such that the voltages supplied by these amplifiers to the load impedance are mutually in phase.

Figure 3 of the drawings represents one embodiment of the system according to the invention. It comprises a class B amplifier 1 which is connected to the input terminals 12 and 13 of an impedance inverting network 14 whose surge impedance amounts to $R/2$. The output terminals 15 and 16 have connected to them a class C amplifier 4 whose threshold value exceeds the unmodulated carrier wave amplitude. Furthermore, a class C amplifier 2 having a threshold value which is lower than the unmodulated carrier wave amplitude is connected to the input terminals 17, 18 of an impedance inverting network 19 whose surge impedance also amounts to $R/2$. To the output terminals 20 and 21 of this network 19 is connected another class C amplifier 3 whose threshold value exceeds the unmodulated carrier wave amplitude. This class C amplifier 3 is furthermore connected to the input terminals 22, 23 of an impedance inverting network 24 whose surge impedance amounts to ¼R and between the output terminals 25 and 26 of which is connected the common load impedance ⅛R which is connected at the same time in parallel with the class C amplifier 4.

So long as the instantaneous value of the modulated carrier oscillation is located below the threshold value of the class C amplifiers, solely the class B amplifier supplies energy to the load impedance ⅛R. Since the load impedance is connected to the class B amplifier via an impedance inverting network 14 with a surge impedance $R/2$, the latter amplifier is loaded during this period of time with an impedance

$$\frac{\frac{1}{4}R^2}{\frac{1}{8}R}=2R$$

At the moment when the instantaneous value of the carrier oscillation is such that the class B amplifier is fully loaded and, consequently, the output voltage of the class B amplifier has attained the maximum permissible value, the threshold value of the class C amplifier 2 is surpassed and in this case this amplifier also supplies energy to the load impedance ⅛R with the result that the impedance 12 to 13 of the class B amplifier decreases and the anode current of the latter increases without any increase of the output voltage. At the moment when the instantaneous value of the carrier oscillation is such that the class C amplifier is fully loaded and, consequently, also the output voltage of the class C amplifier has attained the maximum permissible value, the class B and class C amplifier 1 and 2, respectively, supply the same amount of energy to the load impedance ⅛R, which involves that the impedance between the terminals 12 and 13 amounts to R and that the load impedance betwen the load terminals 17 and 18 also amounts to R.

At this moment the threshold value of the class C amplifiers 3 and 4 is surpassed and the load impedance of the amplifiers 1 and 2 decreases still further owing to the fact that the amplifiers 3 and 4 also supply energy to the load impedance ⅛R. At the maximum instantaneous value of a 100% modulated carrier oscillation, the amplifiers 3 and 4 are also fully loaded and the load impedance of the amplifiers 1 and 2 betwen the terminals 12, 13 and 17, 18, respectively, has decreased to the value ½R whilst also the amplifiers 3 and 4 are loaded in this case with an impedance ½R. All the four amplifiers supply in this case the same amount of energy to the load impedance ⅛R. Now, all amplifiers are fully loaded and operate with an efficiency which is equal to the maximum efficiency of a class B amplifier which is about 63–67%.

A system equivalent to the system according to Figure 3 is represented in Figure 4. The latter may be derived from the former by replacing the network 24 with the load impedance ⅛R between the input terminals 25, 26 by the network 24 in Fig. 4 wherein a load impedance

$$\frac{\frac{1}{4}R^2}{\frac{1}{8}R}=\frac{1}{2}R$$

is connected in series with the input terminals 22, 23.

Figure 5 represents a practical example of the system according to Figure 3. In Figure 5 the amplifiers 1, 2, 3 and 4 are represented, comprising amplifier tubes 41, 42, 43 and 44 respectively, the anodes of which are coupled to the respective filter circuits by means of coupling condensers 45, 46, 47 and 48. Each impedance inverting network 14, 24 and 19 consists of a π filter the series impedance of which consists of an inductance 14′, 24′ or 19′, respectively, and the cross-impedance of which consists of the parallel connection of a condenser and an inductance.

The condenser and the inductance which are located between the input terminals of the network 14 are denoted by 28 and 29, respectively. The condenser and the inductance which are located between the output terminals 15 and 16 of the network 14 and between the output terminals 25, 26 of the network 24 are united to form a condenser 30 and an inductance 31. In a similar manner the condenser 32 and the inductance 33 form the cross-impedances of the neighboring networks 24 and 19. The cross-impedance connected between the terminals 17 and 18 of the network 19 is represented by the condenser 34 and the inductance 35. Each of the previously mentioned cross-impedances is tuned so as to form for the carrier-wave frequency a capacitive reactance which is equal to the inductive reactance of the corresponding series impedances 14′, 24′ and 19′, respectively. Although cross-impedances only consisting of a condenser would suffice, it is advantageous, in view of the suppression of the harmonics of the carrier wave, to utilize the above-mentioned parallel connection of a condenser and an inductance.

Figure 6 represents one embodiment of the system shown in Figure 4, which needs no further explanation. It is obvious that the currents supplied by the amplifiers 1, 2, 3, and 4 to the load impedances ⅛R (Figure 3) and ½R respectively (Figure 4) must be in phase. Since the networks 14, 24 and 19 each bring about a phase displacement of 90° the oscillations to be amplified must, consequently, be supplied to these amplifiers via phase-displacing networks, in such manner that between the oscillations supplied to the amplifiers 1 and 2 there exists a phase displacement of 90° whilst between the oscillations supplied to the amplifiers 1 and 4 or 3 and 4 respectively there exists a phase displacement of 90°.

Although it is believed that my invention has now been made clear to those versed in the art and that further illustration thereof is unnecessary, I have shown in Figure 7 a circuit arrangement such as shown diagrammatically in Figure 3. In Figure 7, I have shown how the several amplifiers are coupled by the networks without having any tube cathodes operating at high-radio-frequency potentials and thus without the use of inductive couplings. The operation of the arrangement of Figure 7 has been described above and need not be repeated here. It is noted, however, that the blocking condensers BC are of sufficient size as to operate as short circuits for the radio-frequency potentials, whereby cirsuits 54, and 64 are seen to be operating in parallel and, therefore, can be constituted in practice by a single capacity and a single inductance. The same remark applies to networks 74 and 84.

In place of shunt direct-current supply as shown in Fig. 7, I may use series supply, if plate voltages for all of the tubes are to be the same. In this case the direct-current blocking condensers BC are omitted.

What is claimed is:

1. In a modulated wave amplifier, a load circuit, four electron discharge tube amplifiers each having output electrodes and input electrodes, means coupling the output electrodes of one of said tubes directly to said load circuit, a phase inverting network coupling the output electrodes of a second one of said tubes to said load circuit, a second phase inverting network coupling the

output electrodes of a third one of said tubes to said load circuit, a third phase inverting network coupled to said second phase inverting network to couple the output electrodes of the fourth one of said tubes to said load, means for impressing modulated wave energy on the input electrodes of each of said tubes in such phase that the outputs of said tubes are cumulative in said load, means for biassing the second of said tubes for class B operation, and means for biassing the remainder of said tubes for class C operation.

2. An amplifier as recited in claim 1, wherein the remainder of said tubes are so biassed that the fourth one of said tubes becomes operative below carrier amplitude and the said one tube and third tube become operative for amplitude values above carrier amplitude.

3. An amplifier as recited in claim 1 wherein the input electrodes of said second and third tubes are excited by modulated wave energy of a first phase, the input electrodes of said one tube are excited by modulated wave energy of a phase equal to said first phase +90° and the input electrodes of said fourth tube are excited by modulated wave energy of said first phase +270°.

4. A system for amplifying a modulated oscillation, which is suitable for the final stage of a transmitter and comprises four amplifiers of which one amplifier operates as a class B amplifier and the other amplifiers act as class C amplifiers with threshold values which are for one of these other amplifiers smaller and for the remaining other amplifiers larger than the unmodulated carrier wave amplitude comprising, means for impressing modulated oscillations on said amplifiers, an impedance inverting network having input terminals coupled to said class B amplifier and having output terminals coupled to one of the class C amplifiers of high threshold value, a second impedance inverting network having input terminals coupled to the said class C amplifier with the lowest threshold value and having output terminals coupled to the other class C amplifier of high threshold value, a third impedance inverting network, a coupling between said last named class C amplifier of high threshold value and said third network, a coupling between said third network and the other class C amplifier of high threshold value, and a load impedance in one of said last two couplings, the surge impedance of the first and second networks being about double the surge impedance of the third network and the load impedance being adjusted to cause each of said amplifiers to work into equal effective output impedance at a load equal to twice the unmodulated carrier, the said various amplifiers being supplied with modulated oscillations of such a phase that the voltages supplied by the amplifiers to the load impedances are of like phase.

5. A system for amplifying a modulated oscillation, which is suitable for the final stage of a transmitter and comprises four amplifiers of which one amplifier operates as a class B amplifier and the other amplifiers act as class C amplifiers with threshold values which are for one of these said other amplifiers smaller and for the other two of said other amplifiers larger than the unmodulated oscillation amplitude comprising, means for impressing modulated oscillations on said amplifiers, an impedance inverting network having input terminals coupled to the class B amplifier and having output terminals coupled to one of the said two class C amplifiers of high threshold value, a second impedance inverting network having input terminals coupled to the class C amplifier with the lowest threshold value and having output terminals coupled to the other class C amplifier of high threshold value, a third impedance inverting network, a coupling between said other and last named class C amplifier of high threshold value and said third network, a coupling between said third network and said one class C amplifier of high threshold value, and a load impedance in said last named coupling, the surge impedance of the first and second networks being about double the surge impedance of the third network and being substantially equal to four times as large as the load impedance, the various amplifiers being supplied with modulated oscillations of a phase such that the voltages supplied by the amplifiers to the load impedance are of like phase.

6. A system for amplifying a modulated oscillation, which is suitable for the final stage of a transmitter and comprising four amplifiers of which one amplifier operates as a class B amplifier and the other amplifiers act as class C amplifiers with threshold values which are for one of these amplifiers smaller and for the other amplifiers larger than the unmodulated carrier wave amplitude comprising, means for impressing modulated oscillations on said amplifiers, an impedance inverting network having input terminals coupled to the class B amplifier and having output terminals coupled to one of the said class C amplifiers of high threshold value, a second impedance inverting network having input terminals coupled to the said class C amplifier with the lowest threshold value and having output terminals coupled to the other of said class C amplifiers of high threshold value, a third impedance inverting network, a coupling between said last named other class C amplifier of high threshold value and said third network, a load impedance in said last coupling, and a coupling between said third network and said one class C amplifier of high threshold value, the surge impedance of the first and second networks being about double the surge impedance of the network and being substantially equal to the load impedance, the various amplifiers being supplied with a phase such that the voltages supplied by the amplifiers to the load impedance are mutually in phase.

7. A system as claimed in claim 4, wherein each of the impedance inverting networks consists of a π filter whose series impedance is formed by an inductance and whose cross-impedance is formed by the parallel connection of an inductance and a condenser.

8. A system as recited in claim 4, wherein each of the impedance inverting networks consists of a π filter whose series impedance is formed by an inductance and whose cross-impedance is formed by the parallel connection of an inductance and a condenser and wherein adjoining cross-impedances of adjacent networks have elements in common.

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