

March 27, 1934.

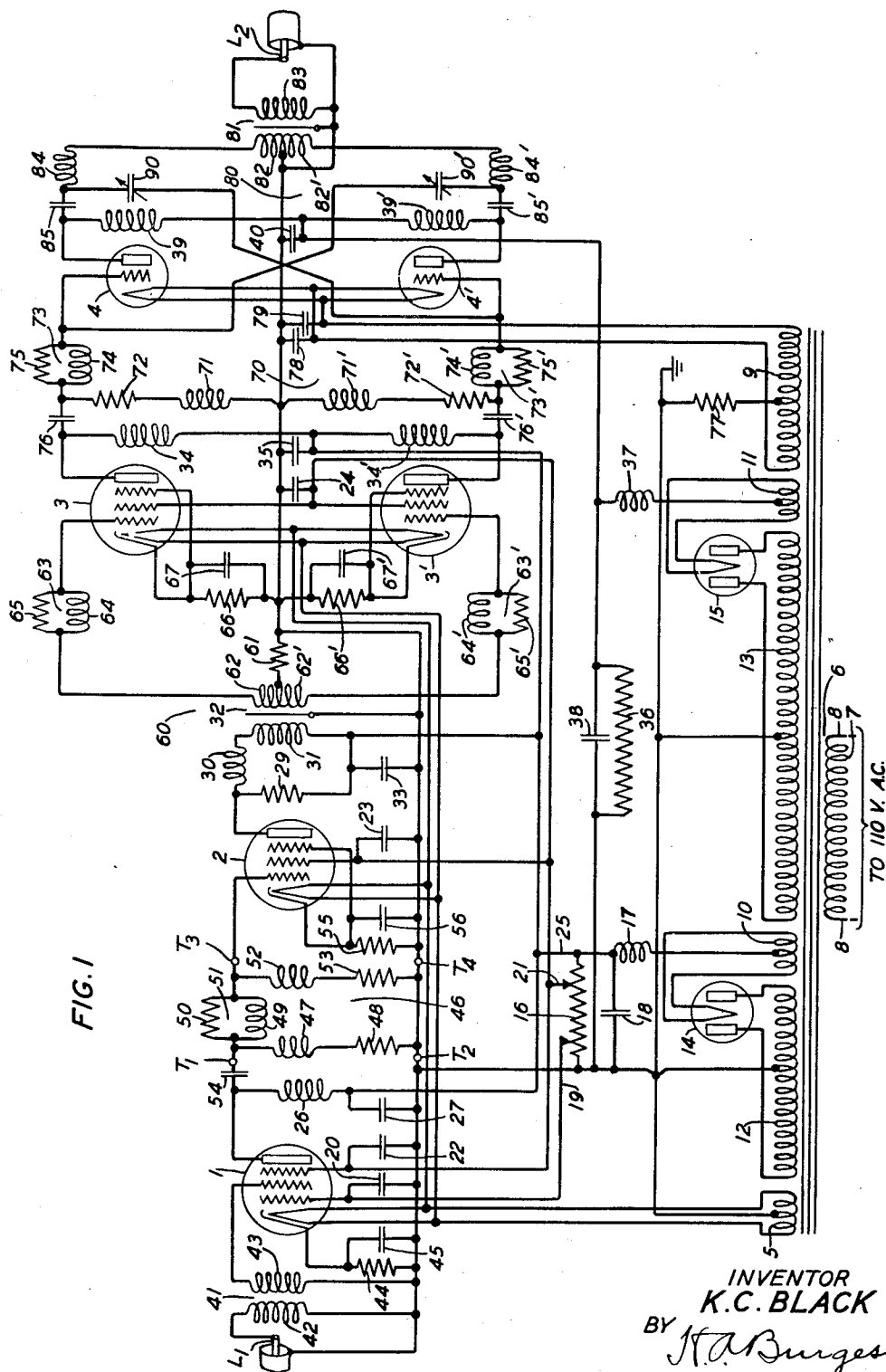
K. C. BLACK

1,952,579

WAVE TRANSLATING SYSTEM

Filed Sept. 2, 1932

3 Sheets-Sheet 1



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WAVE TRANSLATING SYSTEM

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3 Sheets-Sheet 2

FIG. 2

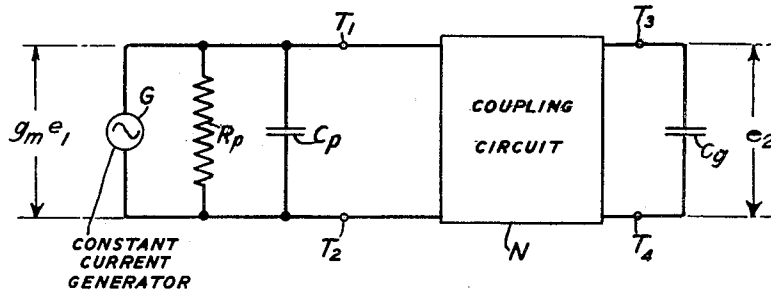


FIG. 3

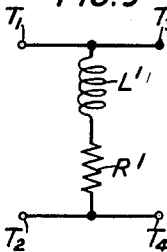


FIG. 4

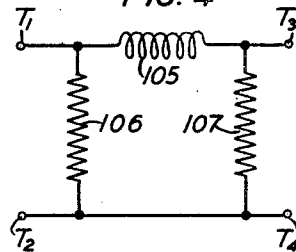


FIG. 5

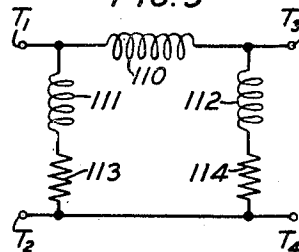


FIG. 6

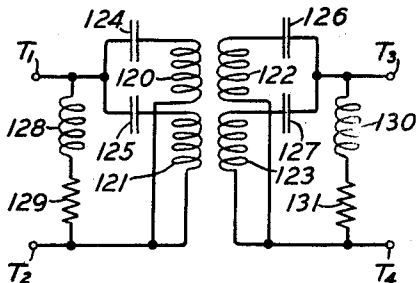


FIG. 7

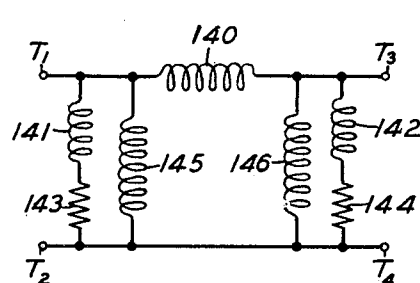
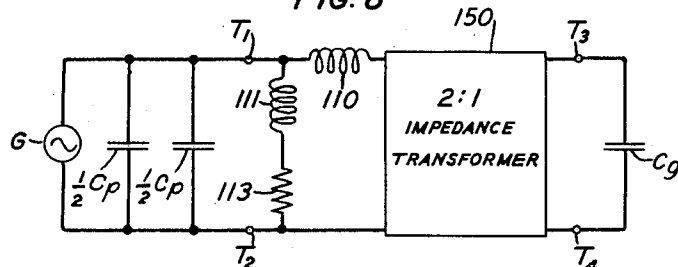


FIG. 8



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3 Sheets-Sheet 3

FIG. 10

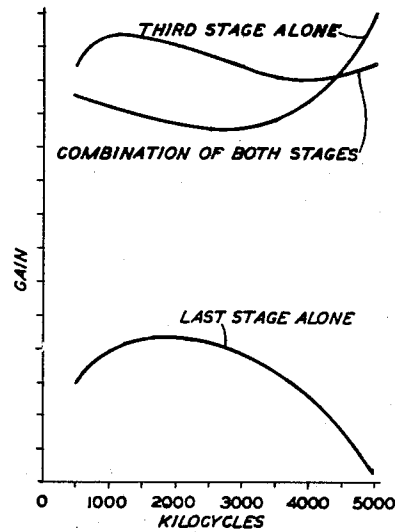


FIG. 9

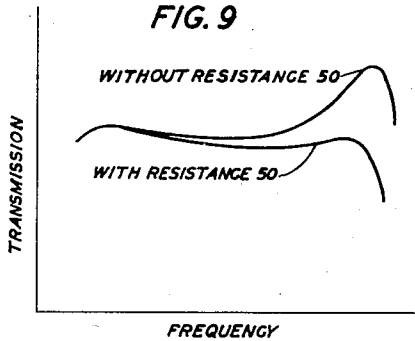


FIG. 11

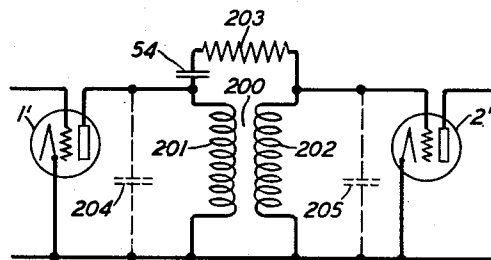
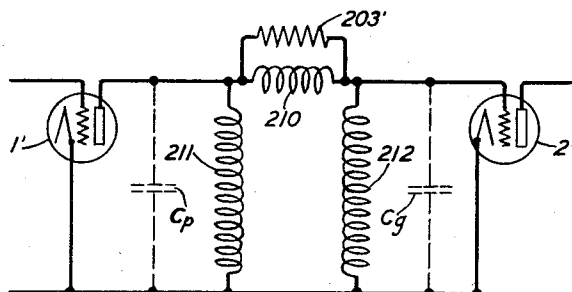


FIG. 12



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UNITED STATES PATENT OFFICE

1,952,579

WAVE TRANSLATING SYSTEM

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Application September 2, 1932, Serial No. 631,486

10 Claims. (Cl. 178—44)

This invention relates to wave translating systems, as for example vacuum tube amplifiers for long cable circuits of wide frequency range. Such circuits may be used for instance for multi-
5 plex carrier communication. They may be, for example, of a length of the order of one or more thousand miles. Each may have, for example, two concentric or coaxial conductors transmitting a very large number of communications, for instance telephone communications, occupying a
10 frequency range extending for example from 500 kilocycles to 5,000 kilocycles.

An object of the invention is to amplify waves of broad frequency ranges extending up to high frequencies, as for example the range from 500
15 kilocycles to 5,000 kilocycles, for instance in circuits such as those referred to above.

In one specific aspect the invention is a vacuum tube amplifier for effecting such amplification with high gain, as for example 60 decibels gain, at the top frequency, and with the ratio of gain to line attenuation at least proportionally as great, approximately, at all of the other utilized frequencies as at the top frequency. To
20 obtain such coupling between voltage amplification stages as will result in high voltage step-up from the grid of one tube to the grid of the next and yet result in an approximately flat gain-frequency characteristic for the gain between the two grids over the utilized frequency
30 range, an interstage coupling circuit is used which comprises a filter separating the inherent plate-to-ground and grid-to-ground capacities of the coupled stages and using a portion of each of those capacities as elements of the filter, and which has means building out the remaining portions of those capacities to terminating resistances for the filter. The coupling circuit may be
40 described somewhat more specifically as a broad band wave filter terminated in resistances equal to its image impedances, the filter having initial and final shunt arms separated by a series arm, each shunt arm including a capacitance, these capacitances being portions of the inherent plate-to-ground and grid-to-ground capacities of the
45 coupled stages, and the remaining portions of the two latter capacities being built out to form the terminating resistances, just mentioned. Each of these two capacities can be built out to a resistance by shunting the capacity with series-connected inductance and resistance of appropriate values, for example; for then the capacity and the inductance form a low-pass filter terminated, (at midseries) by the resistance, (as
50 pointed out in Nyquist Patent 1,894,322, January

17, 1933). The filter thus terminated has its input impedance a resistance over its transmitting frequency range or pass band (as indicated by Fig. 116 (b) on page 227 of "Transmission networks and wave filters", T. E. Shea, D. Van
60 strand Co., N. Y., 1929), provided the filter is terminated in an appropriate value of resistance at its input end as well as at its output end so that it works between its midshunt and midseries image impedances.

A feature of the invention is an inherently reactive wave source feeding two paralleled filters, each passing a given frequency band, each using a portion of the source reactance as filter reactance and each forming a terminating resistance for the other.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 shows an amplifier illustrative of the specific aspect of the invention referred to above;

Fig. 2 gives a general picture of an interstage coupling system;

Figs. 3 to 8 show examples of specific forms of coupling circuits;

Figs. 9 and 10 show curves facilitating explanation of the invention;

Fig. 11 shows a transformer type of interstage vacuum tube coupling system embodying a feature of the invention; and

Fig. 12 shows a filter type of interstage system that is equivalent as regards operating results.

Fig. 1 shows a four-stage vacuum tube amplifier for amplifying waves received from line L_1 and transmitting the amplified waves to line L_2 . The lines L_1 and L_2 are shown as sections of a concentric conductor or coaxial conductor cable with the outer conductor grounded. The first stage of the amplifier comprises a screen grid, space charge grid, heater type vacuum tube 1 having a mutual conductance of 10,000 micromhos, for example; the second stage comprises a heater type pentode 2 having a mutual conductance of 3,000 micromhos, for example; the third stage
100 comprises two tubes 3 and 3' connected in balanced or push-pull relation, each tube being the same as tube 2; and the fourth stage comprises two power triodes 4 and 4' also in push-pull relation, each of high transconductance and low
105 interelectrode capacities, and producing relatively low modulation, and each for example of 100 watts power capacity or dissipating 100 watts in the plate circuit.

The filaments of tubes 1, 2, 3 and 3' are ener- 110

gized in parallel from a five-volt secondary winding 5 of power transformer 6, which has primary winding 7 connected to a 110-volt, 60-cycle power source 8 and has a 10-volt secondary winding 9 energizing the filaments of tubes 4 and 4' in parallel. Transformer 6 also has secondary windings 10, 11, 12 and 13. Windings 10 and 11 energize the filaments of rectifier tubes 14 and 15, respectively. Winding 12 and rectifier 14 supply direct current to resistance 16 through a filter comprising choke coil 17 and by-pass condenser 18.

Resistance 16 has a 15-volt tap 19 supplying voltage to the space charge grid of tube 1, by-pass condenser 20 suppressing fluctuations in this voltage.

Resistance 16 has a 180-volt tap 21 supplying voltages to the screen grids of tubes 1, 2, 3, and 3', by-pass condensers 22, 23 and 24 suppressing fluctuations in these voltages.

Resistance 16 has a 250-volt tap 25 supplying space current for tubes 1, 2, 3 and 3'. The space current is supplied to tube 1 through choke coil 26, condenser 27 by-passing variations. The space current is supplied to tube 2 through a branched circuit comprising as one branch resistance 29 and as the other branch inductance 30 in series with primary winding 31 of unbalanced to balanced interstage transformer 32, condenser 33 by-passing variations. The space current is supplied to tubes 3 and 3' through choke coils 34 and 34', respectively, condenser 35 by-passing variations.

Winding 13 and rectifier 15 supply 1,000-volt direct current to bleeder resistance 36 through a filter comprising choke coil 37 and by-pass condenser 38; and the voltage across resistance 36 is applied to the plates of tubes 4 and 4' through choke coils 39 and 39', respectively, condenser 40 by-passing variations.

The control grid of tube 1 is grounded, for direct current, through the secondary winding 43 of amplifier input transformer 41, which has its primary winding 42 connected to line L₁. The cathode of the tube is connected to ground through resistance 44 and by-pass condenser 45 which supply biasing potential for the control grid.

The control grid of tube 2 is at ground potential for direct current, being connected to ground through a branched circuit formed by elements of a filter interstage coupling circuit 46 described hereinafter. One of the branches comprises inductance 47 and resistance 48 in series with each other and with parallel-connected inductance 49 and resistance 50, elements 49 and 50 forming a series arm 51 of filter 46; and the other branch comprises inductance 52 and resistance 53 in series. The capacities employed in the filter are obtained from the inherent plate-to-ground capacity of tube 1 and the effective input capacity of tube 2. A stopping condenser 54 of negligible reactance separates the plate of tube 1 and the control grid of tube 2 for direct current. The cathode of tube 2 is connected to ground through resistance 55 and by-pass condenser 56 which supply biasing potential for the control grid.

The control grid of tube 3 is at ground potential for direct current, being connected to ground through elements of interstage coupling circuit 60 that couples tube 2 to tubes 3 and 4. The elements forming this ground connection comprise resistance 61 in series with secondary winding 62 of transformer 32 and with a branched circuit 63 composed of inductance 64 and re-

sistance 65 in parallel. The cathode of tube 3 is connected to ground through resistance 66 and by-pass condenser 67 which supply biasing potential for the control grid.

The control grid of tube 3' is at ground potential for direct current, being connected to ground through elements of the interstage coupling circuit 60. The elements forming this ground connection comprise the resistance 61 in series with secondary winding 62' of transformer 32 and with a branched circuit 63' composed of inductance 64' and resistance 65' in parallel. The cathode of tube 3' is connected to ground through resistance 66' and by-pass condenser 67' which supply biasing potential for the control grid.

The control grid of tube 4 is at ground potential for direct current, being connected to ground through elements of interstage coupling circuit 70 (described hereinafter) that couples tubes 3 and 3' to tubes 4 and 4'. The elements forming this ground connection comprise inductance 71 in series with resistance 72 and with a branched circuit 73 composed of inductance 74 and resistance 75 in parallel. Stopping condenser 76 separates the plate of tube 3 and the grid of tube 4 for direct current. Elements 71' to 76' function in connection with tube 4' as elements 71 to 76 function in connection with tube 4. The filaments of tubes 4 and 4' are connected to ground through winding 9 and resistance 77 bypassed by condensers 78 and 79, the resistance 77 supplying biasing voltage for the grids of tubes 4 and 4'.

An output circuit 80 (described hereinafter) couples tubes 4 and 4' to line L₂. The circuit 80 comprises a permalloy dust core balanced to unbalanced push-pull transformer 81 which has primary windings 82 and 82' and secondary winding 83, the winding 82 having in series there-with an inductance 84 and a stopping condenser 85, and the winding 82' similarly being in series with an inductance 84' and a stopping condenser 85'. The transformer changes the impedance level to 80 ohms corresponding to the impedance of the line L₂. Condensers 90 and 90' are cross-neutralizing condensers which neutralize the coupling effects of the grid-plate capacitive coupling and other inherent coupling between the output circuit and the input circuit of the last stage of the amplifier. The stopping condensers 85 and 85' isolate the high frequency transformer 81 from the high direct current plate voltage.

The inductances 84 and 84' are small coils which separate the tube and transformer capacities and thereby improve transmission at the top frequency as indicated hereinafter.

An amplifier such as that of Fig. 1 may need to meet requirements for example such as the following:

- (1) That it transmit a frequency band of 500 kilocycles to 5000 kilocycles;
- (2) That the gain be approximately 60 decibels at the highest frequency, and that at all utilized frequencies the gain be at least as great as the attenuation in the line;
- (3) That the noise introduced by the amplifier be less than the resistance noise introduced by the line; and
- (4) That the amplifier be such that in the last stage tubes can be used of sufficient power capacity to hold modulation below objectionable values, as for example, tubes of the 50-watt class (e. g. of the power capacity of the Western Electric Company type 211-D tube).

Regarding requirement (4), if the amplifier can meet the other requirements with 50-watt tubes in the last stage, then if desired tubes of higher power capacity could be used without necessitating any radical change in the type of amplifier circuit employed but with only such minor rearrangements as required by higher direct current voltages, increased currents, etc. The amplifier would still meet requirements (1) to (3) when the tubes of increased power capacity were used.

Regarding requirement (3), the gain required at the top frequency is taken as approximately the line attenuation to be counteracted by the amplifier at that frequency. In many cases it is desirable that a substantial portion of this gain, for example a 20 decibel voltage step-up, be obtained in the input transformer in order that the resistance contribution of noise from the first tube and its associated circuit will be below the required value. The type of the tube and the circuit of the tube control this figure for the amount of voltage step-up that the input transformer must give in order that the additional voltage gain from the grid of the first tube to the line L_2 will never have to be so great as to cause the amplifier noise to equal the resistance noise introduced by the line. If the required amplifier gain at the top frequency is 60 decibels and the transformer 81 gives a voltage step-up of, say 20 decibels at that frequency, the voltage gain from the grid of tube 1 to the line L_2 will never have to exceed 40 decibels.

The original power level in the line will be regarded as the reference level and designated zero power level. For example, assuming the line attenuates the top frequency 60 decibels before delivering it to the amplifier, for that frequency the signal voltage level on the line at the amplifier input will be -60 decibels.

The line attenuation decreases with frequency, for example, from 60 decibels at 5000 kilocycles to approximately 20 decibels at 500 kilocycles. In order that after passage through the amplifier all utilized frequencies will be at their original power levels it will usually be desirable to employ a line attenuation equalizing network (not shown), but it is advantageous to obtain a substantial amount of the total required equalization in the input transformer, by tuning the input transformer to the top frequency and having the utilized frequency range fall on the low frequency side of the resonance curve, since then the voltage step-up of the transformer at the top frequency can be made high due to the tuning. The transformer may have a low coupling coefficient and act as a rather dull single tuned circuit with the maximum step-up at the top frequency.

With the amplifier working very close to the limiting tube noise level, it is in some cases desirable to have the input transformer perform only a portion of the equalization effected by the amplifier and to have the remainder performed by one or more of the voltage amplification stages rather than in or ahead of the input transformer; so that the low frequencies of the utilized range will be transmitted to the grid of tube 1 at a voltage level sufficiently high to insure that they will override the noise. (Equalization in a voltage amplification stage means that only at the top frequencies does the signal approach as close to the noise level as permissible and that the lower frequencies are always maintained at a higher power level relative to

the resistance noise; whereas equalizing the line characteristic entirely before the amplifier tubes has the disadvantage that the signals of all frequencies are reduced to a point where they are equally near the resistance noise level of the line. The seriousness of amplifier noise increases with the number of amplifiers in tandem.) Moreover, the design of the transformer for maximum gain at the top frequency is in some cases facilitated by lessening the amount of equalization required in the transformer and accordingly performing a substantial proportion of the equalization later in the amplifier. However, it will be assumed that a substantial amount of equalization is to be effected in the input transformer 41 and that the amplifier characteristic from the grid of tube 1 to the line L_2 is to be substantially flat. It has been found that the required gain and equalization in the transformer 41 can be obtained with an air core transformer whose secondary winding 43 tunes the effective input capacity of tube 1, as well as the inherent capacity of the attached wiring, to resonance at the top frequency. The primary winding 42, of insulated wire, is wound directly on the low alternating current potential end of the secondary winding 43, also of insulated wire. If desired, loading resistance (not shown) can be incorporated in the winding 43 or connected in series with it, to control the equalization. For example, a large diameter transformer with a primary-to-secondary turns ratio of about 1 to 6 and a loading resistance of 100 ohms in series with the secondary winding was found to have a desirable transmission characteristic. If desired, the transformer 41 instead of being of the air core type, may have a core of permalloy dust, introducing effective resistance of appropriate value to provide the desired equalization in the transformer.

The transformer 41 forms substantially a short circuit on the line L_1 at very low frequencies, and thereby prevents low frequency interference from entering the amplifier and modulating the high frequency signal on the grid of tube 1.

Passing from consideration of the input system of the amplifier of Fig. 1, the voltage amplification stages of the amplifier will now be considered. The gain of such a stage, or of a tube and its associated interstage coupling circuit that couples it to the following tube, is usually expressed as the ratio of the voltages on the grids of the consecutive tubes or may be expressed in decibels as $20 \times$ the logarithm of this ratio, this expressing true decibel gain (of power) if the circuits feeding the consecutive grids are of the same impedance. Use of screen grid tubes (as for example, tubes 1 and 2) facilitates obtaining high gain over the utilized frequency range without necessity for employing neutralizing connections to prevent impedances placed in one stage (for instance, the stage comprising tube 1) from being in effect short-circuited by impedances of later stages reflected back through the grid-plate capacity of a tube (for instance, tube 2).

For amplifying wide frequency ranges extending up to high frequencies it has been found that (assuming adequate screening) at least when a stage does not employ neutralization or regenerative or negative impedances, for a given mutual conductance and plate-to-ground capacity of the tube of the stage the higher the internal plate resistance of the tube the greater becomes the gain of the stage (either for an approximately

flat gain-frequency characteristic over a given frequency range or for some other shape of characteristic, for instance, a characteristic with a peak at some particular frequency of the utilized range), though little improvement is obtained by increasing the plate resistance after it has reached twenty times the load impedance. With the utilized frequency range broad and extending up to high frequencies, as for example, in the case of the 500 kilocycles to 5000 kilocycles range, the frequency range practically determines that interstage impedances will be low compared to the tube impedances. In other words, very little of the actual u of the tube (for example, tube 1) is used, and the tube may be considered as a constant current generator acting across a capacity which is the plate-to-ground capacity of the tube. Then the higher the impedance that is built up in the plate circuit (this impedance must include the tube capacity in shunt), the higher the gain. Since the generator delivers a constant current, the gain in voltage ratio is directly proportional to this impedance.

Fig. 2 is a generalized showing of the alternating current circuits of an interstage coupling system (such for example, as that comprising tubes 1 and 2 and coupling circuit 46 of Fig. 1), the interstage coupling circuit being shown in block form as a four-terminal network N having input terminals T_1 and T_2 and output terminals T_3 and T_4 corresponding to similarly designated terminals in Fig. 1 and in Figs. 3 to 8. One tube (corresponding, for example, to tube 1 in Fig. 1) is represented by its equivalent circuit, consisting of a constant current generator G of voltage $g_m e_1$ with the plate resistance R_p and the plate capacity C_p connected in parallel with it, g_m being the mutual conductance or transconductance of the tube. The coupling circuit N couples this tube to the second tube (corresponding, for example, to tube 2 of Fig. 1) which is represented by its grid capacity C_g alone. Other effects, for example grid conductance may be neglected here. Further, since, as indicated above, in order to increase gain the resistance R_p is made large compared to the load impedance connected to it, R_p may be regarded as of negligible admittance compared to the load, and thus may be regarded without material error as omitted in considering the system, thus simplifying the system to be considered.

Figs. 3 to 8 show examples of specific forms of coupling circuits which block N may represent (the direct current connections required for supplying plate and grid potentials being omitted as in Fig. 2). Any of these forms may be substituted for the coupling circuit 46 in Fig. 1. The circuit 46 will be described by reference to the circuits of Figs. 2 to 5.

The circuit of Fig. 3 may be called a resistance choke coupling circuit. In the case of this type of coupling C_p and C_g (shown in Fig. 2) are combined and an associated inductance L' tunes with the total capacity at some particular value. A resistance R' is then inserted in the circuit, and over the chosen band of frequency the whole coupling circuit is transformed into a relatively constant impedance. In particular over a considerable part of this range the impedance is a relatively pure resistance. One particular value of R' gives the most uniform transmission characteristic. The resistance choke coupling circuit may be considered as a one-half section low-pass filter which converts the combined grid and plate capacities into a relatively constant impedance over the pass band. Transmission through

the filter is not used, but the input impedance of the filter is used as a coupling impedance.

The gain in this type of circuit is given by the expression $g_m Z$, where g_m is the mutual conductance of the first tube and Z is the coupling impedance, and the coupling impedance is largely determined by the capacity and the highest frequency to be transmitted. The characteristic input impedance of a low-pass filter section is given by the reactance of the capacity at the cut-off frequency and it is usually desirable to have this cut-off at the top frequency to be transmitted. Actually, if the terminating resistance is made about 30% higher than the theoretical value for a filter termination, the impedance throughout the band is essentially constant, and 30% higher than would be obtained by the conventional termination. A feature of the invention is such a resistance choke coupling circuit, the coil tuning the capacity at the top frequency to be transmitted and the resistance being approximately 30% higher than the reactance of either of the other elements at that frequency. This proportioning gives the coupling circuit the highest impedance (not resistance) which is at the same time constant within limits of approximately $\pm 5\%$.

For the time being let it be assumed that the maximum constant impedance is equal to the capacity reactance at the top frequency. Let it also be assumed that $C_p = C_g$. (This limitation simplifies preliminary discussion and is easily removed later.) This means that if X_{cp} is the reactance of the plate side, the coupling impedance in the case of the resistance choke coupling circuit is $\frac{1}{2} X_{cp}$. All wiring, coil, and other capacities are considered lumped with the tube capacities.

If some filter coupling scheme is used it is possible to separate the grid and plate capacities so that it will be necessary to have only one of the reactances to contend with at a time. The first step along this line is to use the circuit shown in Fig. 4, but with resistances 106 and 107 omitted. Here the capacities C_p and C_g (shown in Fig. 2) form the terminating shunt elements of a complete low-pass filter section comprising inductance 105 as the series arm. The characteristic impedance of the filter will be given by X_{cp} . This represents twice the impedance which it was possible to get with the resistance choke coupling circuit. Unfortunately, the characteristic of a filter without resistance termination is by no means flat. In fact, it is essentially a pure resonant coupling circuit. If the filter be assumed perfect and be terminated in physical resistances 106 and 107 equal to X_{cp} at both ends of the line, a very good transmission characteristic can be obtained, but the effective impedance into which the tube must work is now equal to $\frac{1}{2} X_{cp}$ which is no better than that of the resistance choke coupling circuit, and since the filter with physical terminating resistances is more complicated than the resistance choke coupling circuit, it is less desirable.

Putting a physical resistance across the plate capacity is the equivalent of using a tube of much lower R_p and is undesirable and wasteful of gain. In the case of a filter coupling circuit, an improvement over the use of the physical resistance may be made by using a combination of the ideas of the resistance choke coupling circuit and the filter coupling device, as indicated in Fig. 5. Assuming that the resistance choke scheme converts a capacity into a pure resistance

over the pass band of the filter, instead of using a physical resistance termination part of each of the capacities (C_p and C_g) can be used, in conjunction with suitable coils 111 and 112 and resistances 113 and 114 as the terminating resistances. The remainder of the capacities will be used with a coil 110 as a low-pass filter section. The coupling circuit is then as shown in Fig. 5 and the equivalent circuit, assuming that the resistance choke device converts a capacity to a pure resistance, has the configuration shown in Fig. 4. In this case, the transmission characteristic is of the same shape as that for Fig. 4 in which physical resistances are used, but all impedances are increased to double their former value. This contributes, theoretically, a 6 decibel increase in the voltage gain of the stage over the corresponding resistance choke coupling circuit. (In actual practice it is seldom possible to realize all of this gain for various reasons, as for instance, departure of filter impedance from the characteristic impedance as the frequency approaches cut-off. However, practical performance is in at least approximate agreement with the theory, notwithstanding the simplifying assumptions.)

If it is assumed that the filter coupling circuit presents a pure resistance equal to the reactance of its first shunt capacity at the top frequency and that the resistance is also equal to its capacity reactance at the top frequency, both the consideration of the maximum power in the load and the consideration of matching filter impedances and cut-offs demand that one-half of the capacity C_p be converted into resistance by the resistance choke circuit and the other half of capacity C_p be assigned as the first shunt capacity of the coupling circuit.

In some cases in order to get a flat characteristic, it is desirable to use dissipative resistances in accordance with the principle explained in U. S. patent to W. L. Casper, 1,432,965, October 24, 1922, for example, in series or shunt with the series coil of the filter coupling circuit, the coupling circuit 46 of Fig. 1 exhibiting the shunt arrangement of such a resistance 50 across coil 49 by way of illustration. The coupling circuit 46 is otherwise the same as the coupling circuit of Fig. 5. The dissipative resistance merely reduces excessive gain in the region of some particular frequency and does not affect the gain appreciably over the greater part of the range if the proper resistance is used in the proper position. As illustrated by the curves of Fig. 9, which indicate the effect of resistance 50 upon transmission through the coupling circuit 46 for the utilized frequency range, the dissipative resistance can be used to eliminate peaks in the transmission which occur near the top frequency to be transmitted. Since in Fig. 1 the condensers 54 and 27 have negligibly low impedance and the choke coil 26 has negligibly high impedance for the utilized frequencies, these three elements used to facilitate supply of direct current plate and grid potentials do not materially affect alternating current transmission through the interstage coupling circuit between tubes 1 and 2 in the utilized frequency range.

It seldom occurs that C_p and C_g are equal as assumed above. When they differ materially, in place of a filter coupling circuit, such for example, as that of Fig. 5 or the filter coupling circuit 46 of Fig. 1, there can be used a transformer of an impedance ratio corresponding to the ratio between the impedances of C_p and C_g , or if the

impedance ratio is not too high a band-pass transforming filter can be used. A transformer suitable over the frequency range from 500 kilocycles to 5000 kilocycles, for example, is shown in Fig. 6; and a suitable transforming filter is shown in Fig. 7.

The transformer of Fig. 6 is of the type disclosed in the application of E. L. Norton, Serial No. 625,616, filed July 29, 1932, assigned to the assignee of this application, for Wave transmission networks for working out of a resistance shunted by a capacity whose reactance at the top frequency to be transmitted equals this terminating resistance. The transformer comprises primary windings 120 and 121 coupled to secondary windings 122 and 123, respectively, with condensers 124, 125, 126 and 127 in series with windings 120, 121, 122 and 123, respectively. Inductance 128 and resistance 129 build out a portion of the plate capacity C_p to a resistance in the manner in which the inductance L' and resistance R' build out a shunt capacity to a resistance as explained above; and, similarly, inductance 130 and resistance 131 build out a portion of the grid capacity C_g to a resistance.

The transforming filter of Fig. 7, referred to above comprises a single band-pass filter section, having inductance 140 as a series arm. One-half of the plate capacity C_p and one-half of the grid capacity C_g are used, in conjunction with coils 141 and 142 and resistances 143 and 144 as the terminating resistances for the filter (in a manner similar to that in which, as explained above, half of the capacities C_p and C_g are used in conjunction with coils 111 and 112 and resistances 113 and 114 of Fig. 5 to form terminating resistances for the filter of Fig. 5). The remaining half of capacity C_p and the remaining half of capacity C_g are used, in conjunction with coils 145 and 146, respectively, to form the initial and final shunt arms, respectively, of the band-pass filter. It has been found that a fairly uniform characteristic can be obtained with a step-up considerably above the theoretical limiting step-up consistent with the width of band to be transmitted. A circuit corresponding to that in Fig. 7 has been used in cases where the frequency band of 10:1 and a capacity ratio of 2:1 has been used, whereas for a frequency band of 10:1 the impedance ratio theoretically should be limited to 1.04.

In all cases, transforming filters are essentially band-pass filters. Theoretically greater gain is always possible with a band-pass filter than a low-pass because the input impedance is, for a fixed capacity across the input of the filter, given by the expression

$$R = X_{cp} \left(\frac{f_2}{f_2 - f_1} \right) \quad 135$$

for a band-pass filter of pass range f_1 to f_2 as compared with

$$R = X_{cp} \quad 140$$

for a low-pass filter.

Fig. 7 may be considered to represent a uniform band-pass filter as well as a transforming filter. For a 10:1 frequency range this has a 10% greater impedance than that of the low-pass filter for the same input capacity. Another practical advantage of a band-pass filter of this type is that it supplies a path for a plate current to the tube which does not involve resistances, (since the plate source can be connected, for example, in the initial shunt arm, in series with ele-

ment 145, the stopping condenser, such as 54 in Fig. 1, then being connected between arm 145 and arm 140, for example). The 10% improvement in this case applies equally well to comparison with the resistance choke coupling circuit. Essentially, if the band is wide, the shunt coil is tuned to parallel resonance at the lowest frequency to be transmitted and the series coil is tuned to series resonance with the tube capacities. Of course, the coil usually adds capacity and if the contribution of capacity is more than 10 per cent of the total capacity, the result of adding the coil is a net loss in impedance.

A further increase in gain with a filter interstage coupling circuit can be obtained by removing one termination. For example, considering the circuit of Fig. 4 where physical resistances are used in the termination, if the resistance across C_p be omitted, the impedance into which the alternating current plate current flows increases by a factor of 2, thus doubling the voltage that appears on the output grid. To be sure, the characteristic which is largely determined by departures from the ideal filter values of impedance becomes less flat so there are certain arguments against the use of only a single terminal, but in many cases the additional gain makes it distinctly worth while. The termination at the output end can be omitted equally well and the input termination retained in which case the theoretical gain is just as great. The shape of the characteristic is in many cases more desirable, that is, relatively flatter over the whole band and holding up better at the high frequencies, if the termination is thus placed at the input end of the filter instead of at the output end.

In case one terminal is omitted where (as for example in Fig. 5) the termination is a resistance choke combination with one half of the capacity of the tube element, the gain is not as great for the removal of the coil and resistance as in the case just discussed. Removing one termination throws additional capacity into the filter. Then, as shown in Fig. 8, in order to preserve the proper cut-off frequency and impedance values, a step-down transforming network 150 is added of an impedance ratio of 2:1. Thus, by removing one termination in this case, a net voltage step-up of

$$\sqrt{2:1}$$

or 3 decibels, is obtained. Here, as in Fig. 2, the first tube is represented by generator G and capacity C_p , shown here as divided into halves, one half forming with coil 111 and resistance 113 a low-pass filter whose input impedance is used as a resistance termination for the filter formed by the other half of C_p with coil 110, transformer 150 and capacity C_g , this latter capacity representing the second tube as in the case of Fig. 2. As indicated above, the resistance R_p shown in Fig. 1 is negligibly large. Therefore, it has been omitted in Fig. 8. Having the resistance R_p high is advantageous not only from the standpoint of the direct effect upon gain, but also because increase of R_p is usually associated with increased screening, which reduces reflected impedances.

With purely passive networks, this type of coupling is a very advantageous type. Even negative impedance, either actual, as in a dynatron, or effective, as obtained by regeneration, would merely modify the values of the shunt terminal impedances, the same types of couplings being used.

With respect to filter coupling circuits for broad

band amplifiers, such, for example, as that of Fig. 1, it may be noted that in general the simpler the circuits, the better the characteristic impedance for a given top frequency and shunt capacity, so that while flatter characteristics can be obtained, as for instance by m-derived filter sections, they are obtained only at the expense of decreased gain.

Actually, the resistance choke type of circuit referred to above does not convert the shunt capacity to a resistance throughout the pass band. Near the cut-off the input impedance becomes almost entirely capacitive. This usually results in lowering the impedance somewhat if a flat characteristic over a given band is required. However, the loss due to this consideration is not sufficient to negative the advantage of the resistance choke type of termination over a termination constituted by physical resistance.

While the impedance of filter types of coupling can be made greater than that of resistance choke coupling, the latter coupling has the advantage that it does not use transmission through the filter and consequently its phase shift, for transmission between the tubes, is very much less than in the case of a filter coupling circuit. This superior phase characteristic becomes of especial importance in the case of regenerative types of amplifiers.

Regarding the matter of the best distribution of tube capacity between a coupling filter and its termination, it is sometimes advantageous to depart from a 1:1 division or ratio and use the greater portion of the capacity in the termination and the smaller portion in the filter, due to the fact that the impedance across a given capacity can be made somewhat flatter by using a termination about 30% too high. This gives as a best distribution of capacity

$$\frac{(1.3)}{(2.3)} C_p$$

used in the termination and

$$\frac{(1.0)}{(2.3)} C_p$$

used in the coupling filter. Other distributions can be chosen appropriate for characteristics of other shapes.

Regarding the matter of the best distribution of a given amount of capacity between the tubes coupled by a filter type of coupling, as great an unbalance as possible between the plate capacity C_p and the grid capacity C_g is desirable for maximum gain and it is immaterial whether C_p or C_g is the smaller. However, the gain due to such inequality is not very large in practical cases. The gain of a resistance choke coupling stage is unaffected by such inequality.

The interstage coupling circuit 60 that couples tube 2 to tubes 3 and 4 in Fig. 1 is a filter coupling circuit with resistance termination 29 (in place of a resistance choke termination) at the input end, and with no termination at the output, and with permalloy dust core transformer 32 inserted in the filter. This transformer not only changes the circuit from an unbalanced to a balanced circuit, but also changes the impedance level. The coils 30, 64 and 64' are the series coils of the filter network. The resistances 65 and 65' eliminate undesirable peaks in the transmission curve near the upper cut-off, in the manner indicated in connection with the description above of resistance 50 and Fig. 9. The resistance 61 removes irregularities which might be

introduced by slight departures from balance in the transformer.

The interstage coupling circuit 70 that couples tubes 3 and 3' to tubes 4 and 4' in Fig. 1 is a balanced half section of filter coupling whose elements correspond to those of Fig. 7, but one termination is omitted. Thus inductances 34 and 34' correspond to inductance 145; resistances 72 and 72' correspond to resistance 143; inductances 71 and 71' correspond to inductance 141; and inductances 74 and 74' correspond to inductance 140. The resistances 75 and 75' fulfill the function that is fulfilled as described above by resistances 65 and 65' in the preceding stage, or by resistance 50 in the first stage.

Regarding the inductances 84 and 84' in Fig. 1, in the design of transformers for broad band amplifiers, one of the most important problems in many cases is the development of as high an impedance as is possible across a capacity (usually a tube capacity). The impedance that can be obtained across such a capacity is limited to about twice the reactance of the capacity at the top frequency to be transmitted, provided the ratio of top frequency to bottom frequency is large. When a transformer is designed, an allowance for the distributed capacity of the winding to be used across this capacity must be made. This normally adds directly to the tube capacity, and if, as is often the case, tube and transformer capacities are about equal, this reduces by a factor of two the impedance that can be obtained. The use of a series coil such as the coil 84 or the coil 84' of Fig. 1 to separate these two capacities permits a higher impedance to be realized. Considering the transformer as a filter, the above process amounts to adding a half section of low-pass filter at one end of a band-pass filter—a procedure which is permissible in view of the very wide band passed by the transformer which makes it almost a low-pass network.

The use of the series coils is the invention of E. L. Norton, and need not be confined to single transformers but can apply to those of the multiple type referred to above in connection with Fig. 6.

Most of the transformers used in broad band amplifiers, such for example as that of Fig. 1, have a tendency to give their best transmission in the middle of the band, and poorer transmission at both ends. Filter coupling circuits such as those discussed above usually give a "two-hump" characteristic with each hump near the edges of the transmission band. Two such stages, one transformer coupled and the other filter coupled, when connected in tandem can be made to have compensating characteristics in many cases, as for example in the case of the third and fourth stages of Fig. 1. Fig. 10 shows gain-frequency characteristics the two stages may have (with coils 84 and 84' omitted) by themselves, and in tandem. The improvement in transmission is very apparent.

As indicated above in the discussion of filter coupling circuits, it has been found possible to improve the transmission considerably by a shunt resistance around a series coil, the resistance eliminating peaks in the transmission which occur near the top frequency to be transmitted as noted in connection with Fig. 9. A similar idea can be used in connection with a transformer as a coupling element. In some cases it may be desirable to use a transformer of approximately one to one impedance ratio as coupling between stages, as shown in Fig. 11 wherein the unity ratio

transformer 200 comprising primary and secondary winding 201 and 202 couples tubes 1' and 2', and a resistance 203 and stopping condenser 54 in series connect the upper ends of windings 201 and 202. Capacity 204 is the inherent plate capacity of the tube 1', (including the winding capacity of winding 201). Capacity 205 is the inherent grid capacity of tube 2', (including the winding capacity of winding 202). The circuit of Fig. 12 is equivalent to that of Fig. 11 as regards operating results, and is a filter coupling circuit with a resistance 203' corresponding to the resistance 203 of Fig. 11 and to the resistance 50 of Fig. 1. The filter of the circuit of Fig. 12 comprises a series inductance element 210 and two shunt arms. One of the shunt arms consists of an inductance 211 and the plate capacity C_p in parallel. The other shunt arm consists of an inductance 212 and the grid capacity C_g in parallel. If the resistance 203 were omitted from Fig. 11 or the resistance 203' were omitted from Fig. 12, a peak in the transmission characteristic of the circuit of Fig. 11 or Fig. 12 would occur in the region of the top frequencies to be transmitted, such, for example, as the peak in the upper curve in Fig. 9. The addition of the resistance 203 or 203' removes the peak, as indicated, for example, by the lower curve in Fig. 9. That is, as regards operating results, the circuit of Fig. 11 with the resistance 203 omitted is equivalent to the circuit of Fig. 12 with the resistance 203' omitted; and the circuit of Fig. 11 with resistance 203 included is the equivalent of the circuit of Fig. 12 with resistance 203' included.

What is claimed is:

1. The combination with two electric space discharge devices, of a coupling circuit for said devices, said circuit comprising a filter separating the inherent plate-to-ground and grid-to-ground capacities of the coupled devices and using a portion of each of those capacities as elements of the filter, and means building out the remaining portions of those capacities to terminating resistances for the filter.

2. The combination with two electric space discharge devices, of a wave filter having a shunt arm and having an arm connected in serial relation to a grid circuit of one of said devices with respect to a plate circuit of the other device, a capacitance in said shunt arm, said capacitance being a portion of an inherent capacity-to-ground of an electrode of one of said devices, and means for building out the remaining portion of said inherent capacity to a resistance.

3. The combination with two electric space discharge devices, of a wave filter having a shunt arm and having an inductance connected in serial relation to a grid circuit of one of said devices with respect to a plate circuit of the other device, a capacitance in said shunt arm, said capacitance being a portion of an inherent capacity-to-ground of an electrode of one of said devices, and means for building out the remaining portion of said inherent capacity to a resistance, said means comprising inductance and resistance connected effectively in serial relation to each other across said remaining portion of said capacity.

4. A wave translating system comprising a screen grid vacuum tube having a plate circuit, a second vacuum tube having a grid circuit, means coupling said circuits, inherent shunt interstage capacitance in one of said circuits, and

means in said coupling means building out said capacitance to shunt interstage resistance.

5 5. A wave translating system comprising two filters having a portion of their pass bands common, and an inherently reactive wave source feeding said two filters in parallel, each filter using a portion of the source reactance as filter reactance and forming a terminating resistance for the other filter.

10 6. The combination with two vacuum tubes of a broad band wave filter for coupling a plate circuit of one to a grid circuit of the other, terminating resistances for said filter of the order of magnitude of its image impedances, said filter having initial and final shunt arms separated by a series arm, a capacitance in each shunt arm, said capacitances being portions of the inherent plate-to-ground and grid-to-ground capacities of said coupled tubes, and means for building out the remaining portions of the two latter capacities to form said terminating resistances.

20 7. A circuit of substantially constant impedance over a wide frequency range, comprising capacity, and inductance and resistance effectively in serial relation to each other across said capacity, said inductance tuning said capacity at the top frequency of said range and said resistance being approximately a third greater than the reactance of either said inductance or said capacity at said frequency.

30 8. A multistage vacuum tube system for transmitting waves of a wide frequency range, comprising inherent shunt interstage capacity, and inductance and resistance effectively in serial relation to each other across said capacity, said

inductance and capacity tuning at the top frequency of said range, and said resistance being approximately a third greater than the reactance of either said inductance or said capacity at said frequency.

9. A multistage vacuum tube circuit for transmitting waves of a wide range of frequencies, comprising a transformer coupled stage giving higher transmission efficiency in the region of the middle of said range than in the regions of the upper and lower limits of the range, and in tandem with said transformer coupled stage a filter coupled stage giving higher transmission efficiency in the regions of the upper and lower limits of said frequency range than in the region of the middle of the range, whereby the transmission efficiency of the circuit over said frequency range is rendered more uniform than the transmission efficiency of either of said stages alone.

10. A multistage vacuum tube system for transmitting waves of a wide frequency range extending up to high frequencies, comprising two vacuum tubes, a transformer of substantially unity impedance ratio having a primary winding and a secondary winding for coupling said tubes, said transformer and tubes having their combined characteristic of transmission efficiency versus frequency peaked in the region of the upper limiting frequency of said range, and means including a resistance connecting the high potential ends of said windings for removing said peak.

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50	125
55	130
60	135
65	140
70	145
75	150