March 18, 1930. A. GOLLOS 1,751,081

RADIO APPARATUS

Filed May 13, 1929 5 Sheets-Sheet 1

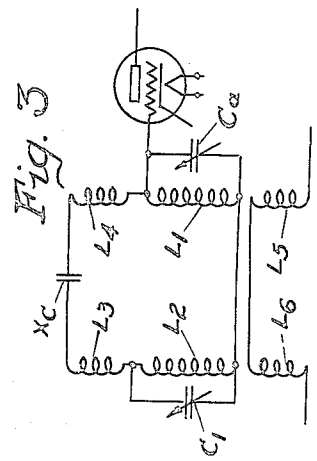


Fig. 3

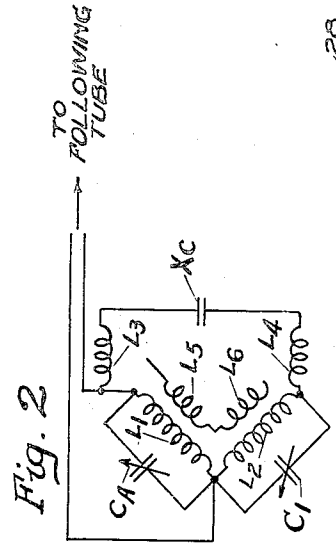


Fig. 2

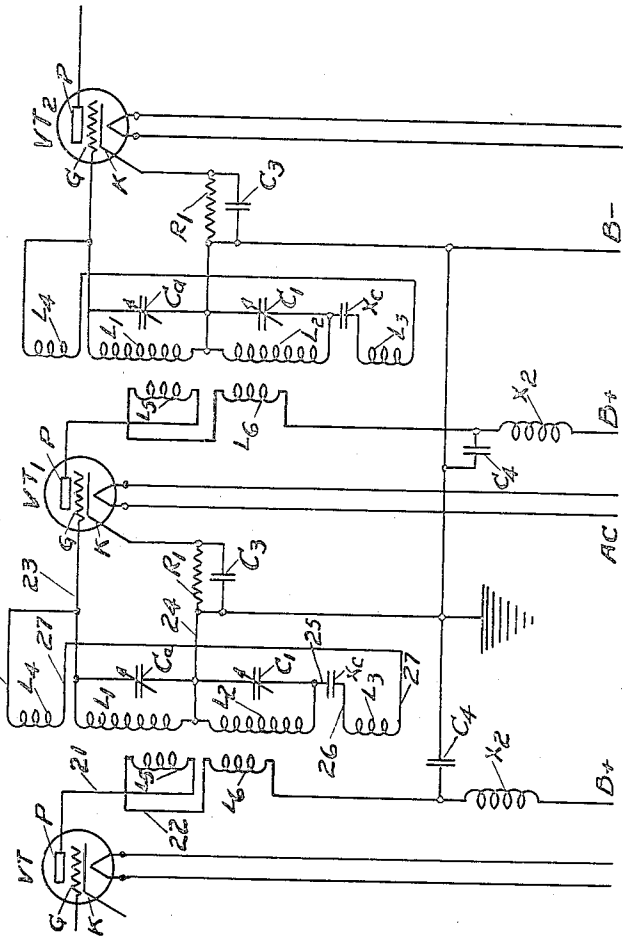


Fig. 1

Inventor
Anatol Gollos
By Geo. E. Walsh
Atty.

March 18, 1930. A. GOLLOS 1,751,081

RADIO APPARATUS

Filed May 13, 1929 5 Sheets-Sheet 2

Fig. 5

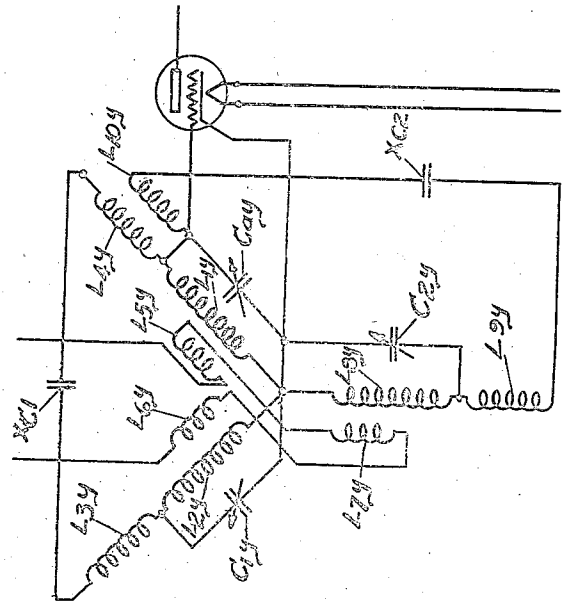
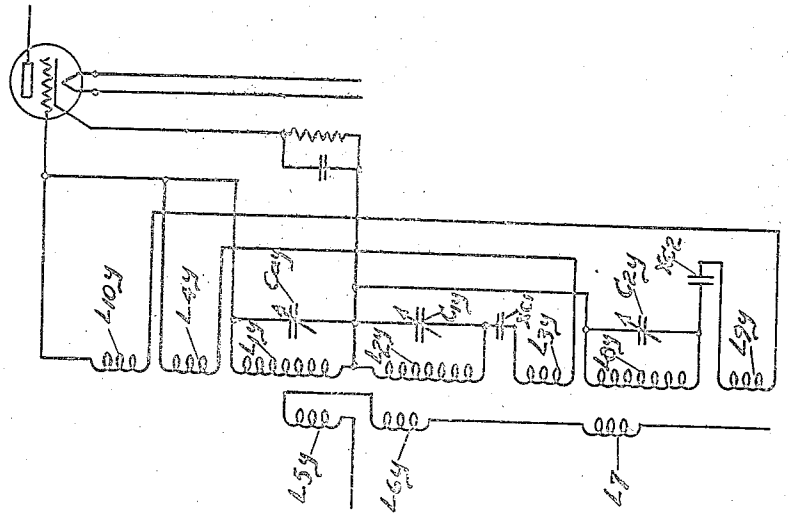


Fig. 4



Inventor
Anatol Gollos
By Geo. E. Wahlen,
Atty.

March 18, 1930. A. GOLLOS 1,751,031

RADIO APPARATUS

Filed May 13, 1929 5 Sheets-Sheet 3

Fig. 6

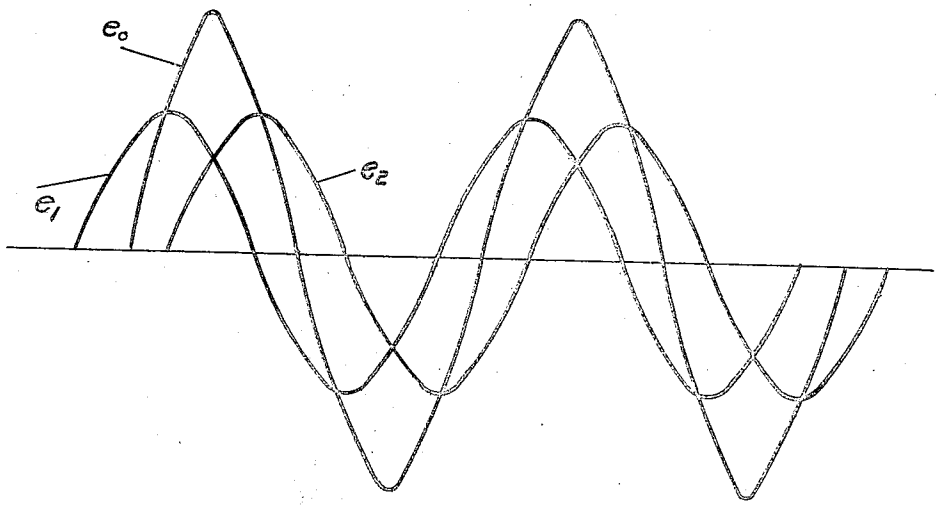
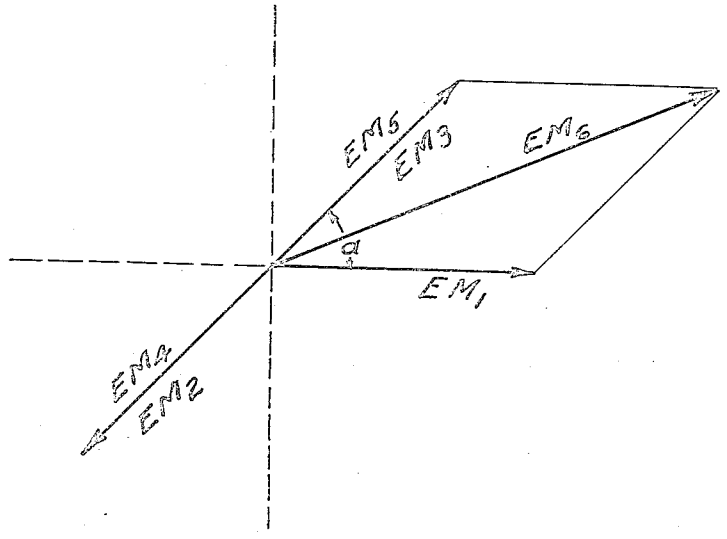


Fig. 9



Inventor
Anatol Gollos
By Chas. Wallace,
Atty.

March 18, 1930. A. GOLLOS 1,751,081

RADIO APPARATUS

Filed May 13, 1929 5 Sheets-Sheet 4

Fig. 7

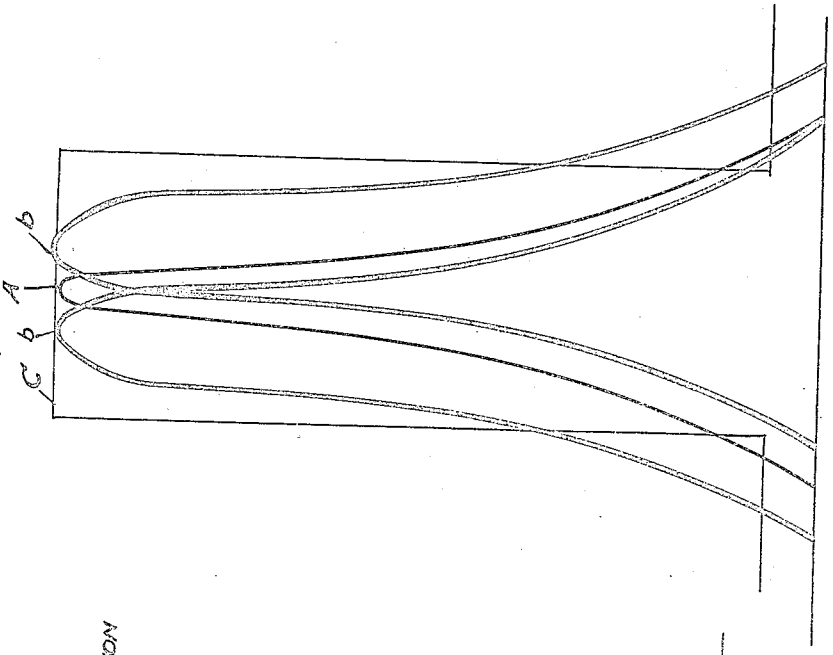
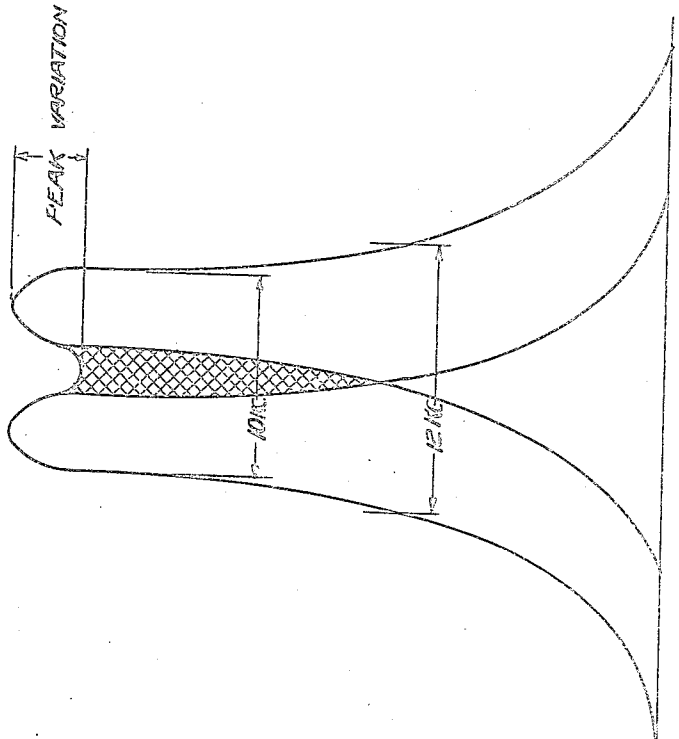


Fig. 8



Inventor
Anatol Gollos
By Geo. E. Wahl
Atty.

March 18, 1930. A. GOLLOS 1,751,081

RADIO APPARATUS

Filed May 13, 1929 5 Sheets-Sheet 5

Fig. 10

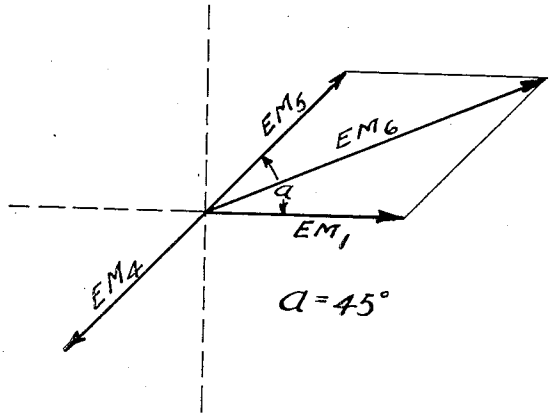


Fig. 11

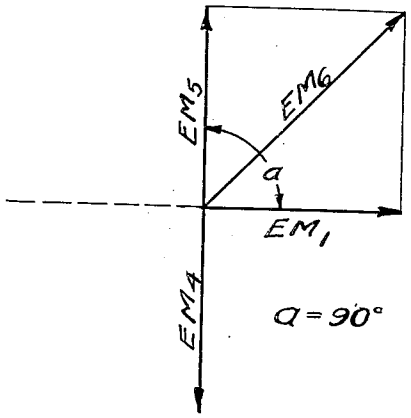


Fig. 12

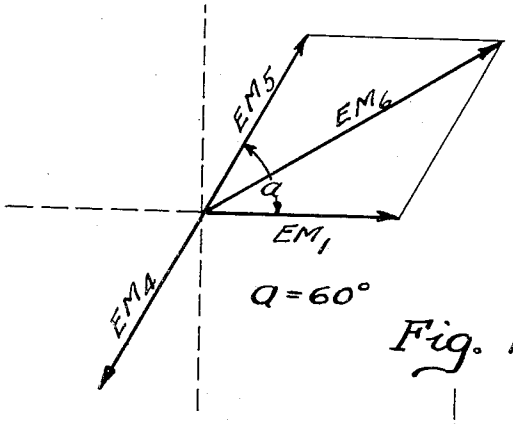


Fig. 13

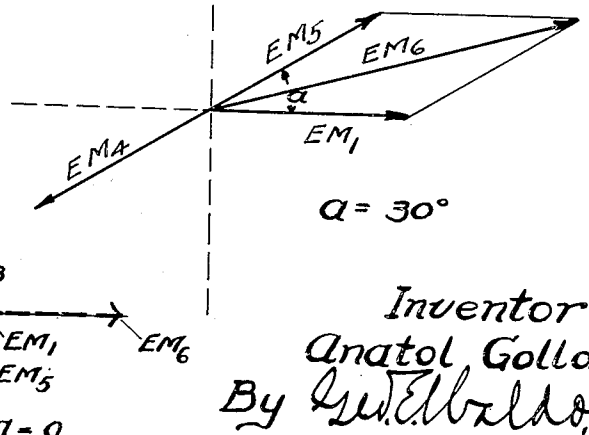
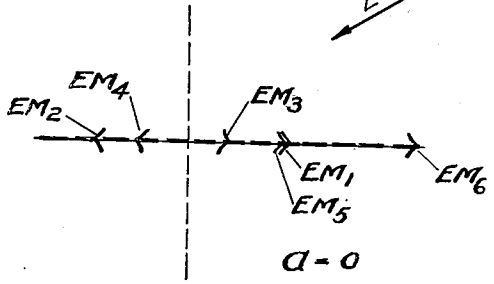


Fig. 14



Inventor
Anatol Gollos
By Geo. E. Beals,
Atty.

Patented Mar. 18, 1930 1,751,081

UNITED STATES PATENT OFFICE

ANATOL GOLLOS, OF CHICAGO, ILLINOIS

RADIO APPARATUS

Application filed May 13, 1929. Serial No. 362,822.

This invention relates to radio apparatus and relates particularly to such apparatus of the multi-phase type.

Principal objects of the invention are to provide a new and novel radio frequency amplifying circuit whereby more energy can be transferred from an electron valve to a succeeding electron valve than by present known circuits of which I have any knowledge, without in any way producing phase distortion or causing a loss of selectivity in the circuit; to provide a band pass system within a predetermined band of frequencies whereby increased and undistorted potential will be impressed upon the input circuit of a succeeding electron valve; and to provide good selectivity and improved tone qualities.

It is commonly known that the voltage appearing in the plate circuit of an amplifier tube is: M Eg (A. C.), where M=amplification constant, and Eg=applied grid voltage (A. C.). Therefore it is apparent that if a higher grid voltage (Eg) is applied, a correspondingly higher plate voltage (A. C.) will appear in the plate circuit, always keeping in mind that the maximum applied potential shall not cause the grid of the succeeding electronic device to swing positive and thus produce distortion. In accordance with my invention, I have devised means for thus applying such higher grid voltages to electronic devices by purely resonant coupling schemes in association with suitable phase shifting devices.

In accordance with the present invention, I attain the foregoing object in the following manner, as fully shown in the accompanying drawings, in which—

Figure 1 is a diagrammatic view showing a preferred system of circuits and controls embodying my invention and improvements as applied to radio receiving apparatus;

Figures 2 and 3 are views substantially similar to Figure 1, showing modified systems of circuits and controls adapted for the practice of my invention as applied to radio receiving apparatus;

Figure 4 is a view substantially similar to Figure 1, showing apparatus having additional phase shifting devices;

Figure 5 is a view showing circuits and controls of radio receiving apparatus of the general type shown in Figs. 2 and 3, having the characteristics of the arrangement shown in Figure 4;

Figure 6 is a vector diagram;

Figure 7 is a comparative diagrammatic view of resonance curves illustrative of present practice and those resulting from the practice of my invention;

Figure 8 is a widened resonance curve tending to show graphically the band pass curves produced by my invention; and

Figures 9 to 14 are vector diagrams.

Describing the operation of the apparatus with particular reference to Fig. 1, potential is impressed upon the input circuit of the first electron valve VT from any source, not shown. This potential may be any form of modulated or unmodulated alternating voltage.

Due to the factor (M Eg) as described above, an A. C. voltage appears in the output circuit of this electronic device and is impressed across the primaries L_5 L_6, and, by ordinary electro-magnetic induction, voltages appear across the circuits L_1 Ca and L_2 C_1 at frequencies at which these circuits are resonant. These voltages differ in phase displacement by an optimum phase difference, which in the diagram (Fig. 1) is 180°. This action is similar to that which takes place in the windings of the commonly known delta-connected transformer used in poly-phase transmission circuits. These voltages which appear across L_1 Ca and L_2 C_1 may be symbolized as E_1 and E_2, respectively.

A clear understanding of the method whereby the phase difference between the two electrical elements E_1 and E_2 (which ap-

pear, respectively, across circuits L_1 Ca and L_2 C_1) may be obtained by reference to Fig. 2, in which the electrical resonance circuits L_1 Ca, L^2 C_1 are laid out to represent the circuit of the standard delta-connected transformer of polyphase transmission type. Now, since the single-phase component flows through L_5 and L_6 without any time lag and since L_5 and L_6 are spaced apart, the voltage component E_1 will appear across L_1 Ca with an appreciable phase lead over that of the voltage component E_2 appearing across L_2 C_1, this phase lead depending on or being varied by the coupling between L_5 L_6. These primaries are preferably spaced somewhat apart so as to avoid coupling between them which would cause one field to oppose the other and cause loss of power. The phase lead E_1 over E_2 is represented vectorially in Figs. 9 and 10, as the maxima EM_1 and EM_2. The circuit L_3 L_4 Xc, Fig. 2, is essentially the same as L_4 L_3 Xc, Fig. 1, but is shown symbolically.

The nature of the invention will be clearly understood by referring to Fig. 1, in which the output from the thermionic amplifier or repeating tube VT is led to the mutual reversed coils L_5 L_6 by means of wire 21, the two coils being opposingly coupled by wire 22. Coupled to L_5 inductively is a coil L_1 which may be tuned to resonant frequency F by the variable condenser Ca, which is shunted across L_1, one side going to the grid of the following repeater tube VT' by wire 23, the other side of this mutual combination L_1 Ca going to resistance R_1, which is used to produce a negative bias on the grid of the following repeater tube to prevent the grid bias from swinging positive and thus producing distortion. The coil L_6 is coupled inductively to the coil L_2 which is tuned to resonance at frequency F by the condenser C_1, a common point of the two condensers Ca C_1 being mutually grounded so as to prevent the effect of body capacity. A common point of the circuit C_1 L_2 is connected to a series condenser Xc by wire 25, the other side of Xc going to mutually coupled coil L_3 by means of wire 26, and a wire 27 connects the other end of L_3 to the reversed coil L_4, which is coupled inductively to L_1, and a wire 28 connects the coil L_4 to the grid of the following repeater tube VT'.

The coupling between L_1 and L_2 is very small due to the fact that L_1 L_2 are opposing. The energy transfer between these two inductances is, therefore, negligible.

Fig. 3 is essentially the same circuit as Fig. 2, but is shown symbolically so as to clear the point of band pass action in which it is clear that circuits L_1 Ca and L_2 C_1 are coupled by the auxiliary circuit L_3 L_4 Xc, and by means of variation in the reactance of Xc, this circuit causes a continual tightening of coupling as frequency decreases, L_5 L_6 in Fig. 3 being coils L_5 L_6 in Fig. 1, but shown symbolically.

Considering the associated circuits L_3 L_4 Xc and symbolizing the voltages that have appeared across L_1 Ca as Em_1 in Fig. 9 and across L_2 C_1 as Em_2, these are shown vectorially differing in phase by angle a.

Now, by magnetic induction due to the physical relationship of the two coils L_2 and L_3, a voltage component appears across L_3, 180° out of phase with EM_2. This is shown in Fig. 9 as EM_3. Therefore, since the circuit L_3 L_4 Xc is near its resonance points, its reactance approaches zero by the law:

$$XL = 2\pi fL$$

$$Xc = \frac{1}{2\pi Fc} \quad (Xc \text{ is negative})$$

at resonance $XL = -Xc \therefore XL + Xc = 0$

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fc}\right)^2} \text{ and}$$

at resonance

$Z = \sqrt{R^2}$, and R being negligible,

$Z = 0$ at resonance (approximately),

where XL = inductive reactance at frequency F

and Xc = capacitive reactance at frequency F,

R = D. C. resistance and Z = impedance at frequency F.

Since the reactance of circuit L_3 L_4 Xc is near zero, and its current maximum a voltage Em_4, (Fig. 9), appears across inductance L_4. But, due to the reversed condition of this coil, Em_4 is 180° out of phase with Em_3 (Fig. 9). Again due to mutual inductance between L_4 and L_1, a voltage component appears across L_1, this voltage being designated Em_5, Fig. 9, being 180° out of phase with Em_4, in phase with Em_3 and out of phase with Em_1 by angle a. Now, by means of the ordinary vector method or trigonometrical method, we combine Em_5 and Em_1 and produce Em_6, the increased voltage applied to the grid of the following electronic device. Thus increased voltage has been actually measured and fully agrees with its theoretical values. Figure 10 shows the method of obtaining this voltage Em_6 vectorially and Fig. 6 graphically. An analysis of the method of combination follows.

Referring to Fig. 6,

Let e_1 = voltage across L_1 Ca, Fig. 1;

Let e_2 = voltage across L_1 Ca, Fig. 1, due to voltage Em_5 as described above;

Then eo=the desired voltage increase applied to tube grid.

Equation of sine wave=$y=a \sin bx$

substituting e for y

Em for a

$\frac{2\pi}{T}t.$ for bx

$\therefore e=Em \sin \frac{2\pi}{T}t.$ or since $\frac{t.}{T}$=frequency

$e=Em \sin 2\pi fT$

Let $w=2\pi f$

$\therefore e=Em \sin wT$

Now let

$e_1=Em_1 \sin wT$ where $w=2\pi f$

$e_2=Em_2 \sin (wT-a)$

then by addition, using trigonometrical law for sum of two lines times constants,

$$eo=\sqrt{(Em_1+Em_2\cos a)^2+(Em_2\sin a)^2}\sin\left(wT-\tan^{-1}\frac{Em_2\sin a}{Em_1Em_2\cos a}\right)$$

Concluding therefore from this equation, it readily can be seen that eo is at all times larger than either e_1 or e_2 with a maximum of e_1+e_2 and a minimum of either e_1 or e_2, eo being the above mentioned quantity Em_6 applied to the input circuits of the following electronic device.

The same result may be shown vectorially in Figure 10.

Let Em_1=maximum value of e_1 in Fig. 6.

Let Em_5=maximum value of e_2 in Fig. 6.

Then the horizontal components of

$$Em_6=Em_1+Em_5\cos a$$

and the vertical components of

$$Em_6=Em_5 \sin a$$

$$\therefore Em_6=\sqrt{(Em_1+Em_5\cos a)^2+(Em_5\sin a)^2}$$

If summation of horizontal components=ΣH

and summation of vertical components=ΣV

$$eo=\sqrt{(\Sigma H)^2+(\Sigma V)^2}\sin\left(wT+\tan^{-1}\frac{\Sigma V}{\Sigma H}\right)$$

it is, of course, understood that Em_6 in Fig. 10=maximum value of eo in Fig. 6, one being the vectorial quantity and the other being the graphical quantity.

It is to be noted in Figure 6 that as angle a becomes larger, eo becomes smaller with a minimum of either e_1 or e_2, and when eo is at a maximum, $a=0$ and $eo=e_1+e_2$.

It is well to note here that in the accompanying circuit, Fig. 1, optimum conditions have been used; that is, e_1 and e_2 are 180° out of phase and angle $a=0$. Therefore Eo applied to following grid is maximum and $eo=e_1+e_2$. The angle a may be varied by varying the coupling between L_5 and L_6, thus varying the voltage applied to the following grid circuit between e_1 or e_2 and e_1+e_2. This is clearly shown in vector diagrams in Figures 11, 12, 13, in which angle a assumes different values and eo becomes larger as a approaches zero.

I have thus without any loss or difficulty produced an increased applied Eg to the input circuit of a following electronic value.

As explained above, the means by which increased amplification is obtained is not dependent upon any one means of producing phase difference and combination; for example, it has been explained that this can be done by using two phases in a three-phase delta connected system. The same effect may be obtained with additional amplification by means of a three-phase star connected system such as is shown in Fig. 4 diagrammatically and in Fig. 5 schematically, the two being essentially the same, the above described system being applicable to a three-phase or any multi-phase appliance, the phases used not being limited in any way.

This is clearly apparent from Fig. 4, in which L_{5y} L_{6y} are similar to L_5 L_6 in Fig. 1, L_{1y} Ca_y L_{2y} C_{1y} being similar to L_1 Ca L_2 C_1, Fig. 1 and the auxiliary circuit L_{4y} Xc_1 L_{3y} being equivalent to L_4 Xc L_3, Fig. 1, the aforementioned so far being the two-phase system. We now add inductance L_{8y} tuned to resonance frequency F by condenser C_{2y}. This auxiliary circuit represents the third branch in the star connected system, while the auxiliary branch Xc_2 L_{9y} and L_{10y} represent an auxiliary band pass system so as to produce similar conditions throughout the band pass circuit, Fig. 5 being essentially the same as Fig. 4, but laid out to represent the common star connected electrical system common to polyphase transmission.

Next referring to Fig. 7, it would be best to describe a problem which has been holding the minds of the radio engineering field. This is the problem of gaining selectivity without producing distortion by the effect commonly known as side-band cutting. It is well known in the art that it is essential to high quality reception that the resonance curve of the tuning apparatus in radio receivers be at least 10 kilocycles wide, the reason for this being that broadcast transmission, as practiced today, is done by modulating the radio frequency carrier wave, which is known as the fundamental, with frequencies varying on both sides of this fundamental from frequencies as low as 60 cycles for the percussion type of instrument to 5000 cycles for the higher pitched reed instruments. This produces a maximum envelope of approximately 10 kilocycles. It would be a tremendous advance in the art if

it were possible to produce a resonant curve which would be 10 kilocycles wide from base to peak, such as is shown in curve C, Fig. 7, instead of the resonance curve A, Fig. 7, which is common to receiving circuits of today and produces a loss in the high notes at resonance, due to a narrowing of the resonance characteristic and a subsequent cutting, of so-called side bands. So far, any endeavor to produce a widening of this common resonance characteristic has produced not only a loss of amplification but also a loss of selectivity, due to the base of the resonant characteristic spreading out. It has to date been deemed an improbability, if not an impossibility, that the perfect resonant curve C, Fig. 7, be even approached.

In my circuit, by a unique method, I have closely approximated the perfect resonance curve, without any attendant loss of either amplification, selectivity or quality. This is done in this wise:—Note in Fig. 1 that there are two associated resonant circuits, L_1 Ca and L_2 C_1. Both of these circuits have sharp resonant characteristics, such as shown in curve a, Fig. 7. However, when these circuits are resonant at the same frequency, these two curves coincide. But if it were possible to produce a slight difference between the peaks of these resonance characteristics, we can produce, by a combination of these two, an approximation of the perfect resonance curve C, Fig. 7. This is shown graphically as curve b, Fig. 7. By varying the difference of these two peaks, we can make the width of the charactristic any predetermined quantity.

The method in which variation between the two resonance peaks is accomplished is described in the following:

Note associated circuits L_3 L_4 Xc in which L_3 is coupled inductively to L_2 and L_4 is coupled inductively to L_1. If we let M represent the mutual inductance between L_2 and L_3, it becomes obvious that, as M increases, the coupling between L_2 and L_3 becomes greater with an increase in energy transfer, but since L_2 and L_3 are fixed, it is advisable to vary M by other means than those mechanical. Note that L_4 is also coupled to L_1 inductively. Let us here represent the mutual inductance between these two coils by the letter M_1. It is evident then that resonance circuits L_1 Ca and L_2 C_1 are coupled by means of the auxiliary circuit L_3 L_4 Xc through mutual inductances M and M_1. Since L_3 L_4 Xc represent an auxiliary circuit of the series resonant type, the amount of energy transferable between L_1 Ca and L_2 C_1 through auxiliary circuit L_3 L_4 Xc is directly dependent upon Xc. It is commonly known in the art that, if two resonance circuits are coupled together inductively, both resonant at the same frequency, they will for one value of coupling produce a single resonant curve such as in Fig. 7, curve a; but as we increase the coupling between these two circuits, the two resonance curves begin to recede from each other and produce a double peaked curve such as in Fig. 7, curve b. In accordance with my invention, this tightening of coupling between the two resonant circuits L_1 Ca and L_2 C_1 is produced by means of increasing the energy transfer between the aforementioned resonant circuits in this manner.

Note associated circuit L_3 Xc L_4. This circuit acts as a link circuit which serves to couple L_1 Ca and L_2 C_1 by means of mutual inductance between L_2 and L_3. Let us designate this M_1. The mutual inductance between L_4 and L_1 is designated M_2. However, since the reactance of the Xc condenser is $Rc=\frac{1}{2fc}$, it is readily seen that its reactance is inversely proportional to freqency.

The energy transfer between L_2 and L_3 is proportional to M_1.

The energy transfer between L_4 and L_1 is proportional to M_2.

The energy transfer between L_3 and L_4 is inversely proportional to Rc and proportional to frequency since

Rc is inversely proportional to frequency and the voltage drop across Xc increases as frequency decreases.

It is plain now then, that as frequency decreases there will be less energy transfer between L_3 and L_4 due to the greater reactance drop across Xc with a corresponding decrease in coupling between L_1 Ca and L_2 C_1 and the production of a narrower band pass curve.

I claim:

1. In a system of the character described, opposed primary inductances adapted to be energized from a common source of radio frequency, tuned secondary inductances each coupled with one of said primary inductances, a vacuum tube having a grid connected to one of said secondary inductances and phase correcting means associated with another secondary inductance for impressing upon the grid a second voltage substantially in phase with the voltage in the secondary inductance connected to the grid.

2. In a system of the character described, a source of radio frequency current, and means for establishing a relatively high potential from said current, comprising a primary winding traversed by said current, said winding having opposed portions, a resonant circuit coupled to each of said portions, said resonant circuits having a common ground and an auxiliary circuit coupled with one of said resonant circuits to receive energy therefrom and coupled with the other of said resonant circuits to induce potential therein complementary to the potential induced therein by the primary winding.

3. In a system of the character described, a source of high frequency alternating current, a vacuum tube having a grid, and means connected to said grid for transferring energy from said source to said grid, comprising a plurality of circuits tuned to resonance at said frequency, means connected with said source for setting up potentials in said circuits that are substantially reversed in phase, and an auxiliary circuit associated with said tuned circuits receiving energy from one of said circuits and by means of the energy received inducing in the other of said circuits an added potential of the same frequency.

4. In a system of the character described, a source of high frequency alternating current, a vacuum tube having a grid, and means connected to said grid for transferring energy from said source to said grid, comprising a plurality of circuits tuned to resonance at said frequency, means connected with said source for setting up potentials in said circuits that are substantially reversed in phase, and an auxiliary circuit associated with said tuned circuits receiving energy from one of said circuits and by means of the energy received inducing in the other of said circuits an added potential of the same frequency and in phase therewith.

5. In a system of the character described, a source of high frequency alternating current, a vacuum tube having a grid, and means connected to said grid for transferring energy from said source to said grid, comprising a plurality of circuits tuned to resonance at said frequency, means connected with said source for setting up potentials in said circuits that are substantially reversed in phase, and an auxiliary circuit associated with said tuned circuits receiving energy from one of said circuits and by means of the energy received inducing in the other of said circuits an added potential of the same frequency, said second named means including a pair of primary windings connected in series with said source and having opposed fields.

6. In a system of the character described, a source of high frequency alternating current, a vacuum tube having a grid, and means connected to said grid for transferring energy from said source to said grid, comprising a plurality of circuits tuned to resonance at said frequency, means connected with said source for setting up potentials in said circuits that are substantially reversed in phase, and an auxiliary circuit associated with said tuned circuits receiving energy from one of said circuits and by means of the energy received inducing in the other of said circuits an added potential of the same frequency and in phase therewith, said auxiliary circuit including capacitative means the reactance of which decreases proportionately to the increase in frequency of the current therein.

7. In a system of the character described, a source of single phase high frequency energy, a vacuum tube repeater having a grid, means for changing said single phase energy to multiphase energy, and recombining the multiphase energy into single phase energy of higher potential, and connections for impressing said energy upon said grid.

8. In a system of the character described, a source of single phase high frequency energy, a vacuum tube repeater having a grid, means for changing said single phase energy to multiphase energy, and recombining the multiphase energy into single phase energy of higher potential, and connections for impressing said energy upon said grid, said means including a plurality of circuits resonant at the same frequency.

9. In a system of the character described, a source of single phase high frequency energy, a vacuum tube repeater having a grid, means for changing said single phase energy to multiphase energy, and recombining the multiphase energy into single phase energy of higher potential, and connections for impressing said energy upon said grid, said means including primary coils connected to set up opposed fields and connected in series.

10. In a system of the character described, a source of single phase high frequency energy, a vacuum tube repeater having a grid, means for changing said single phase energy to multiphase energy, and recombining the multiphase energy into single phase energy of higher potential, and connections for impressing said energy upon said grid, said means including a pair of resonant circuits having a common connection and means for transferring energy to said circuits in opposed phase relation.

11. In a system of the character described, a source of single phase high frequency energy, a vacuum tube repeater having a grid, means for changing said single phase energy to multiphase energy, and recombining the multiphase energy into single phase energy of higher potential, and connections for impressing said energy upon said grids said means including primary coils connected to set up opposed fields and connected in series, secondary coils inductively coupled with said primary coils, and means for reversing the phase of the energy transmitted to one of said secondary coils.

12. A method of radio frequency amplification which consists in causing the plate current of an electron valve to induce in intermediary coils between said valve and a succeeding valve voltages of different phase, inducing voltage in an auxiliary circuit from one of said intermediary coils, inducing voltage in the other of said intermediary coils from said auxiliary circuit and impressing the resultant voltage of said last mentioned coil upon the grid of the succeeding valve.

13. The method of transferring energy from one electron valve to a succeeding electron valve which consists in transferring energy from the output of the first valve to a plurality of resonant circuits and at the same time changing the phase relation of a portion of said energy to the remainder thereof transferring energy from one of said circuits to an auxiliary circuit and shifting the phase of the energy and thereafter transferring energy from said auxiliary circuit to the other of said resonant circuits and from there to the succeeding valve.

14. In a system of the character described, an electron valve having an output circuit, a succeeding valve, resonant circuits coupled with said output circuits to receive multiphase energy therefrom, a resonant auxiliary circuit coupled with said circuits to recombine the multiphase energy into single phase energy, said auxiliary circuit having means for maintaining its coupling with the other circuits such as to give for a definite frequency, a sharp double peaked resonant curve.

15. In a system of the character described, an electron valve having an output circuit, a succeeding valve, resonant circuits coupled with said output circuits to receive multiphase energy therefrom, a resonant auxiliary circuit coupled with said circuits to recombine the multiphase energy into single phase energy, said auxiliary circuit having means for maintaining its coupling with the other circuits such as to give for a definite frequency, a sharp double peaked resonant curve, said last named means including a capacity the reactance of which decreases in proportion to the increase in frequency.

In witness that I claim the foregoing as my invention, I affix my signature this 10th day of May, 1929.

ANATOL GOLLOS.