May 9, 1933. G. L. BEERS 1,907,478

AMPLIFICATION SYSTEM

Filed Nov. 30, 1926 2 Sheets-Sheet 1

Fig. 1.

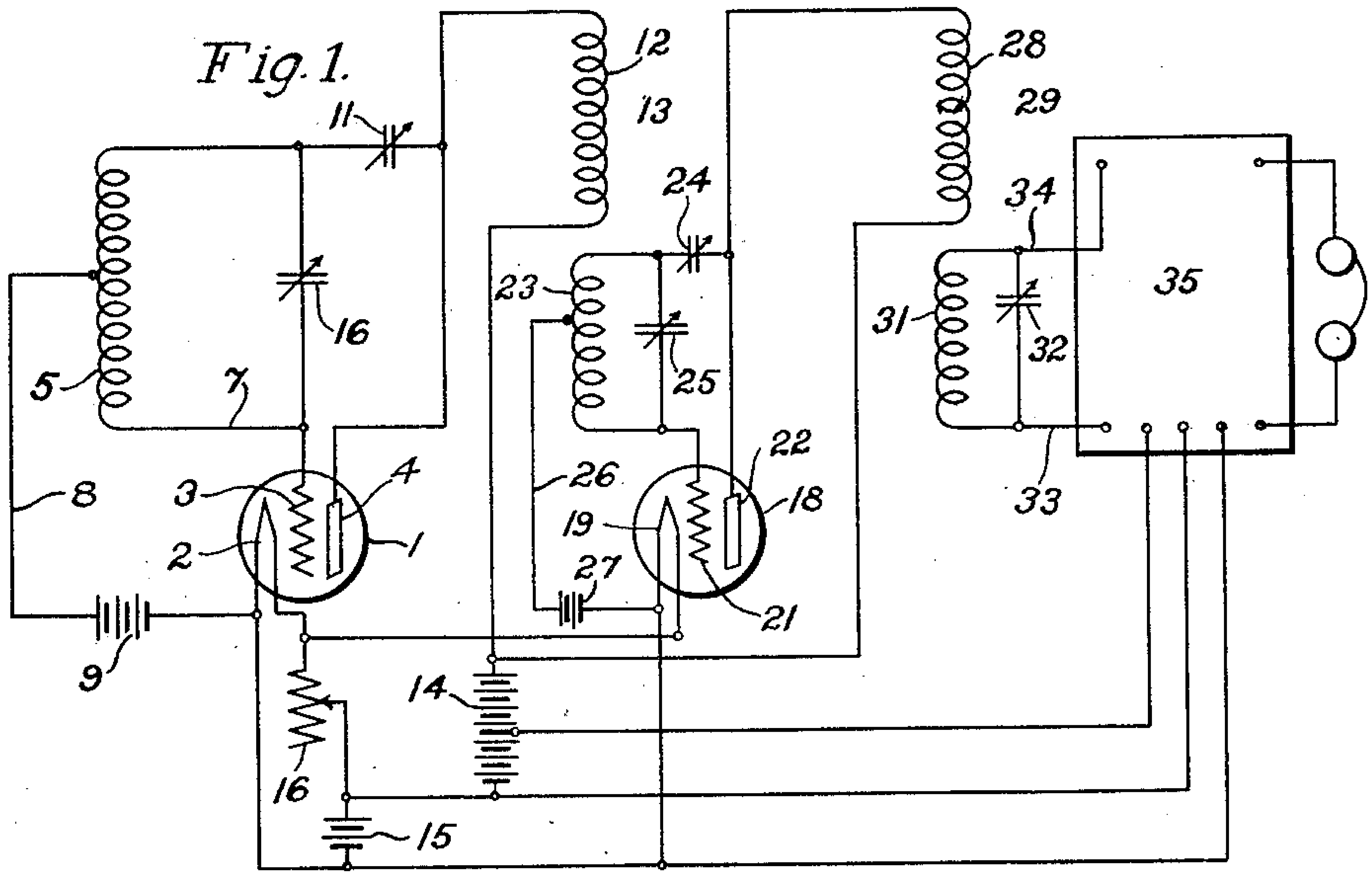

Fig. 2.

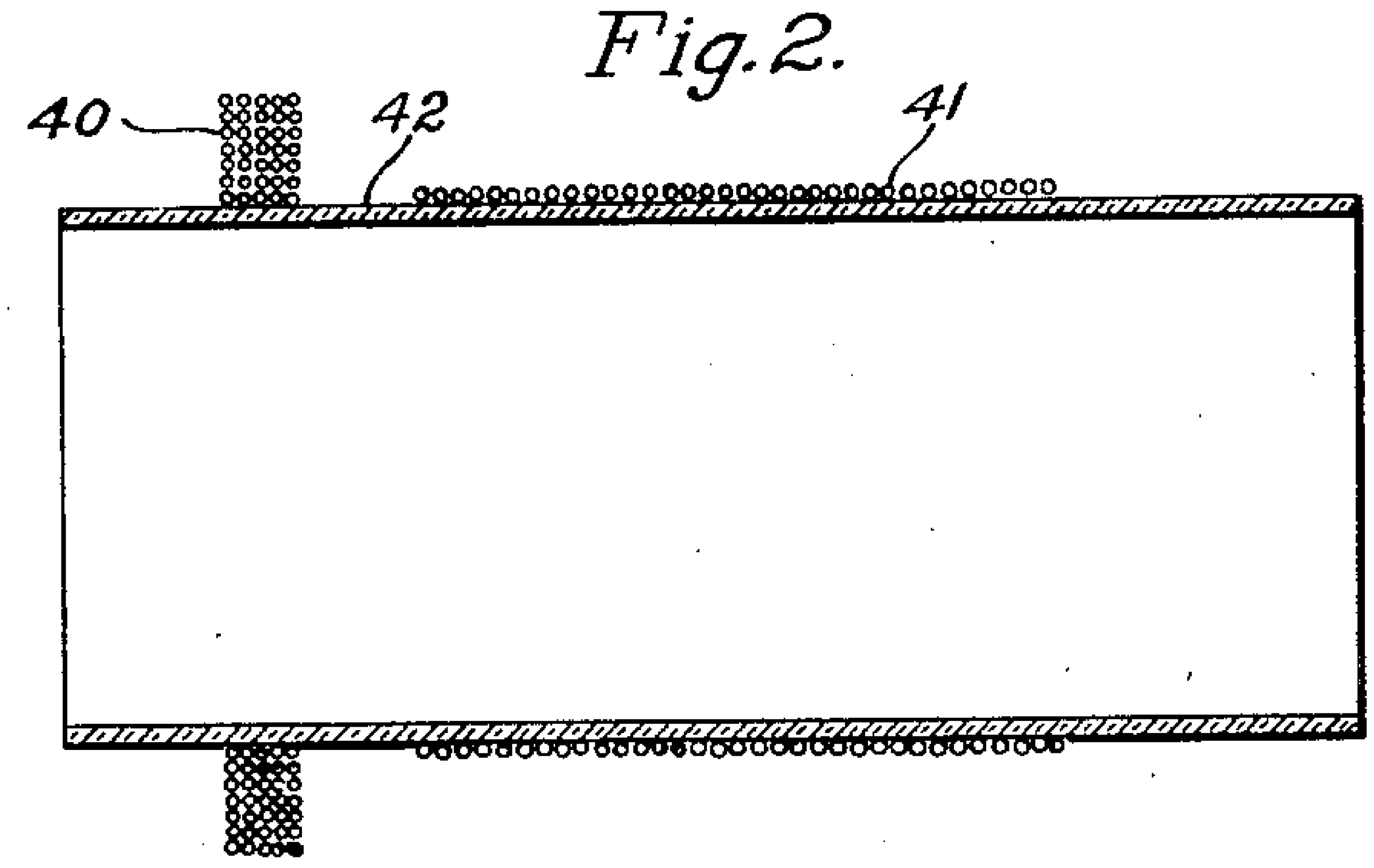

Fig. 3.

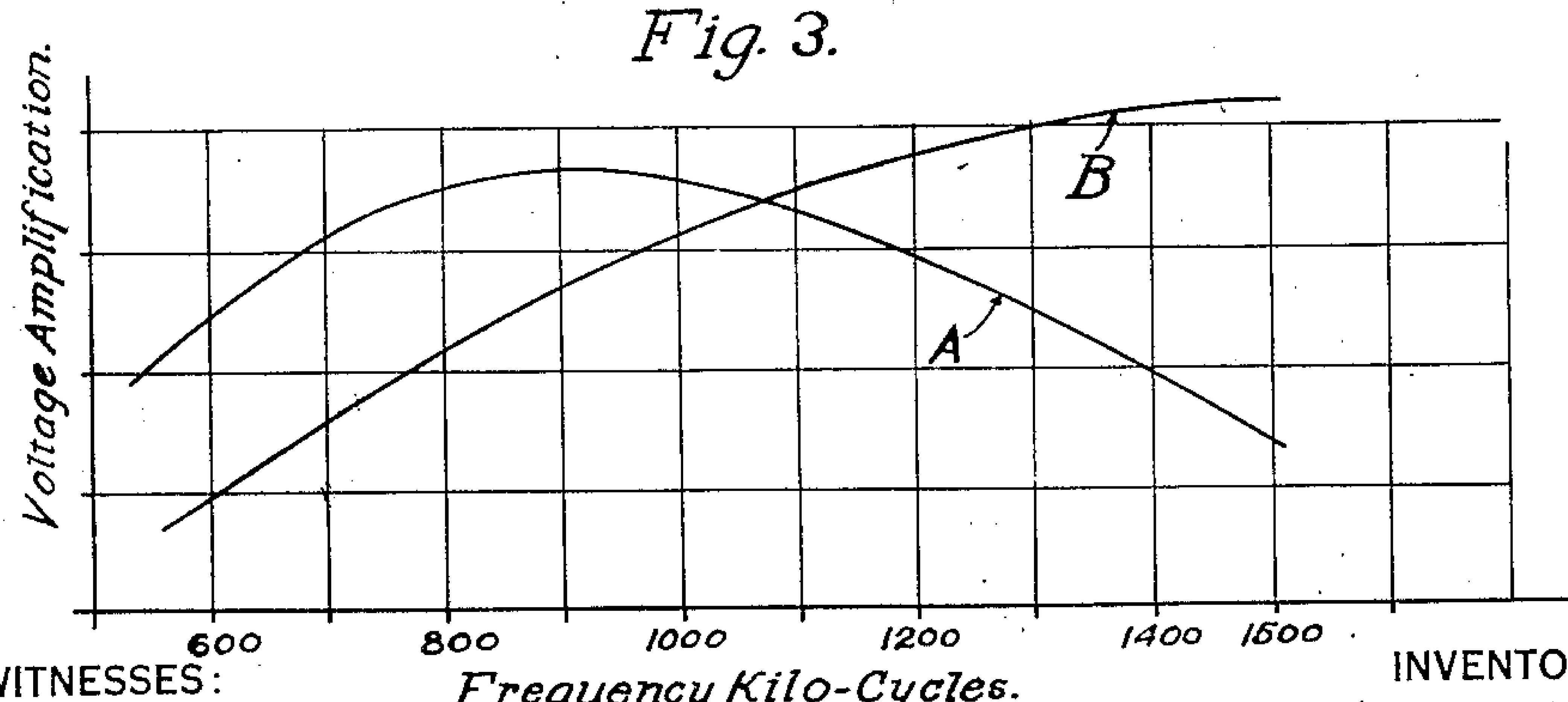

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Fig. 4.

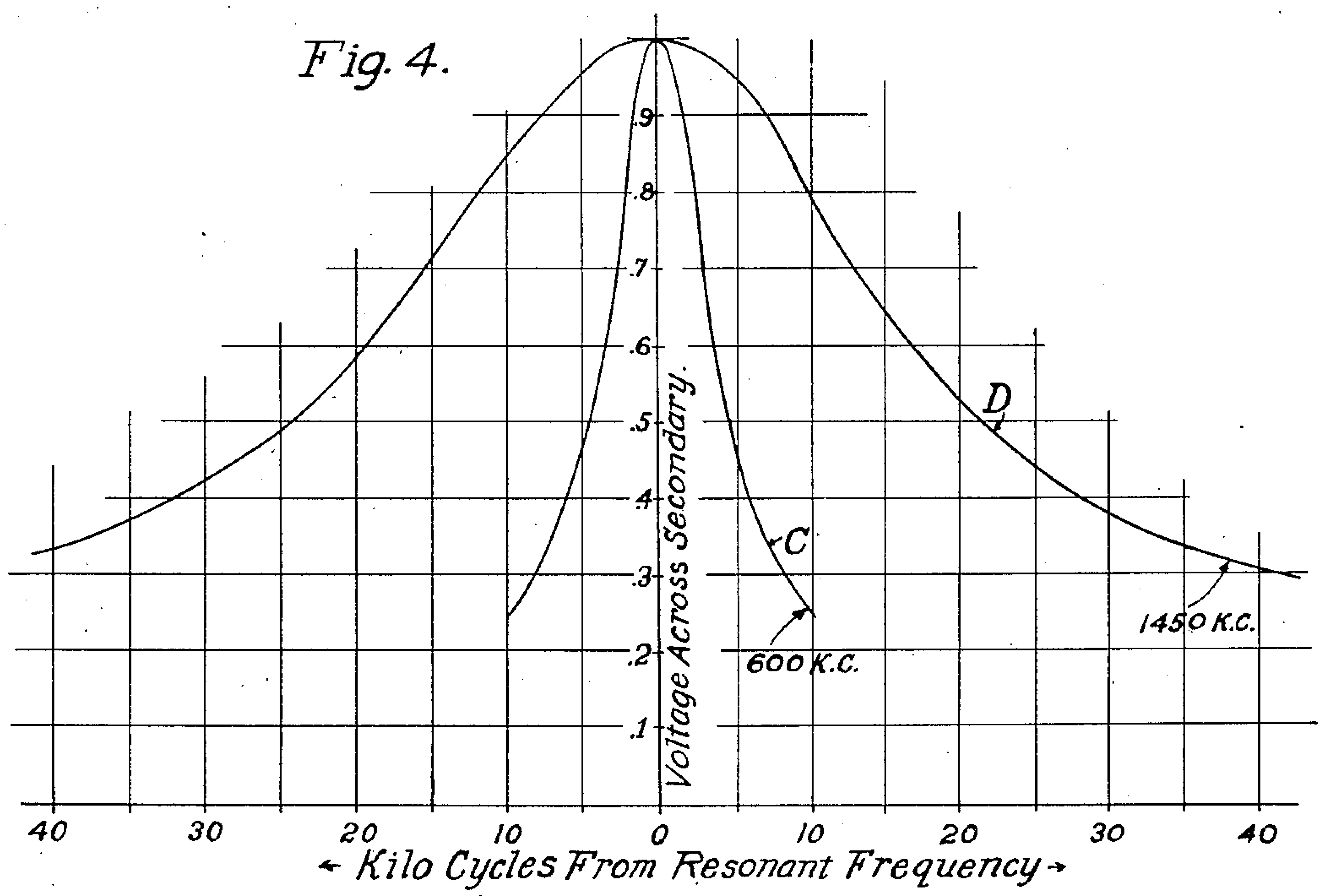
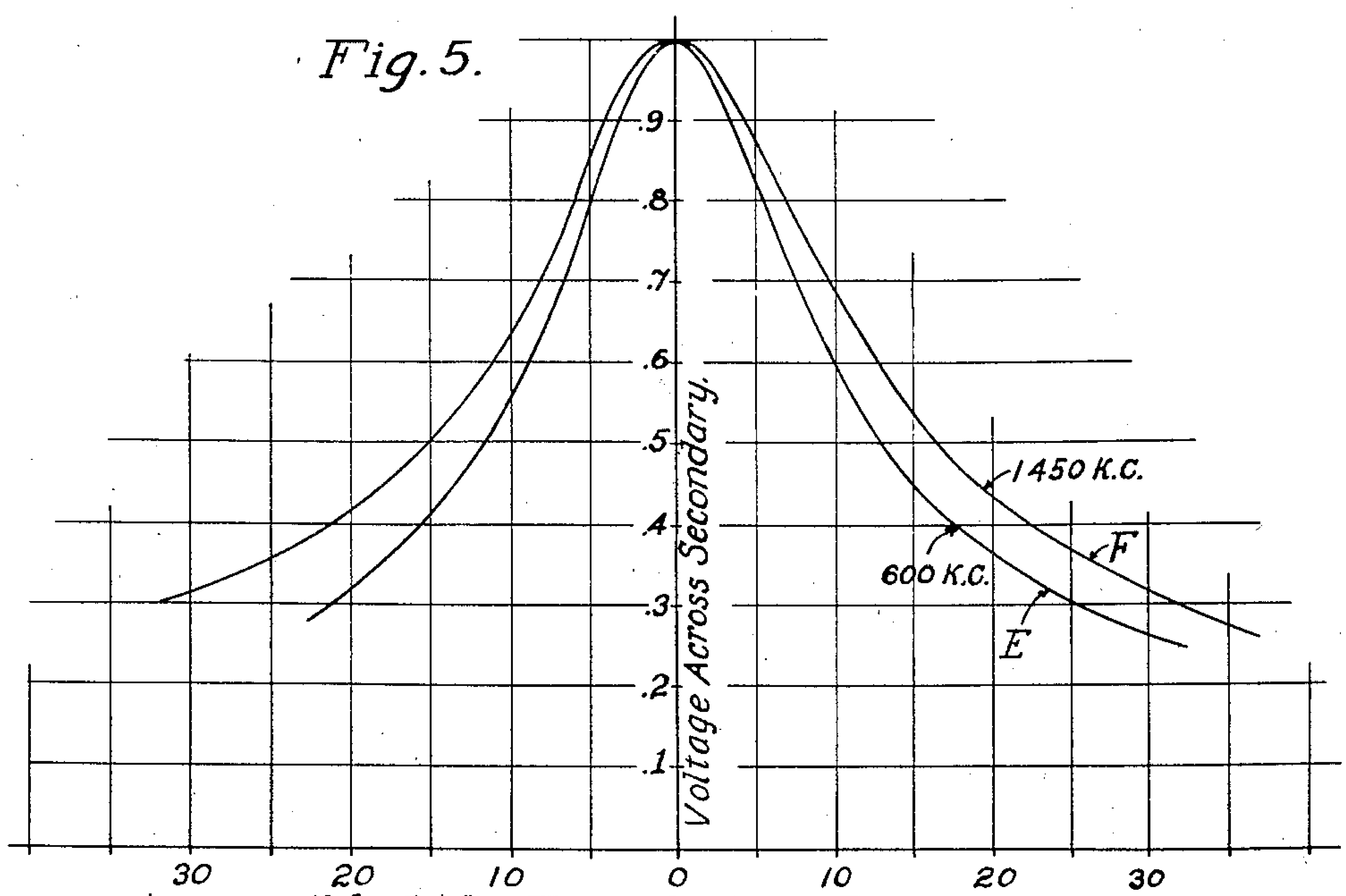


Fig. 5.



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UNITED STATES PATENT OFFICE

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AMPLIFICATION SYSTEM

Application filed November 30, 1926. Serial No. 151,722.

My invention relates to amplification systems, and it has particular relation to a system designed for voltage amplification at radio frequencies.

One object of my invention is to improve the selectivity characteristics of a radio-frequency amplifying system.

Another object of my invention is to improve the voltage amplification characteristics of a radio-frequency amplifying system.

Another object of my invention is to provide an improved radio-frequency transformer.

Another object of my invention is to provide a radio-frequency amplifying system that will be reasonably selective over the entire range of frequencies now used in radio broad-casting, and, at the same time, give a substantially equal voltage amplification over the same range.

Another object of my invention is to provide a radio-frequency amplification system that is inherently stable and does not tend to oscillate over the range of frequencies for which it is designed.

In the construction of radio-frequency amplifiers according to the teachings of the Alexanderson Patent No. 1,173,079, it has been found, by experiment, that the inductance of the primaries of the tuned transformers should be kept low in order to lessen the tendency of the amplifier to go into self-oscillation. It is customary to so proportion the primaries of such tuned transformers that the natural period thereof is somewhat higher than any frequency to which the secondary is intended to be tuned, with the result that, although the amplification at the higher frequencies is satisfactory, the selectivity, by reason of primary resonance and high losses in the secondary, is less good at the high-frequency end of the tuning range than at the low-frequency end.

On the other hand, a radio-frequency transformer of the usual type, having a low-inductance primary, is extremely selective at the lower-frequency end of the range, since the radio-frequency resistance of the secondary is many times less at such lower frequencies than it is at the high-frequency end. With an amplifying system of but one or two stages, the distortion is very pronounced at the lower frequencies by reason of the extreme selectivity preventing the side bands from being efficiently amplified.

In order to efficiently amplify both side bands resulting from modulation by voice and music, it is necessary that the resonance curve, at any given radio-frequency over the tuning range, shall be from 8 to 10 kilocycles wide at 80 or 90% of the peak or resonance-current value.

With radio-frequency transformers of the usual type, input frequencies one, or one and one-half kilocycles above or below the frequency to which the secondary may be tuned at the low-frequency end of the range will give approximately 90% of the resonance current, while, at the high-frequency end of the range, the input frequencies may vary as much as fifty kilocycles above or below resonance and still give secondary currents 90% of the resonance current. The selectivity at high frequencies may be somewhat improved by using several stages, but the improvement is not sufficient to be satisfactory. Even a single-stage amplifier is much too selective for good quality reproduction at low frequencies and this condition is greatly exaggerated in a multi-stage amplifier.

If, therefore, an attempt is made to operate a receiving set of the usual multi-stage, tuned radio-frequency type in the vicinity of a high-powered broadcasting station operating on a frequency which lies toward the high-frequency end of the tuning range, much difficulty is experienced in receiving signals from stations operating on frequencies near that of the local station, at such times as the local station is broadcasting.

Signals from the high-frequency stations, when received without interference, are not appreciably distorted, but distortion is very noticeable on signals from stations broadcasting at frequencies lying toward the lower end of the frequency range.

I have accordingly provided an inter-tube coupling system for use in single or multistep radio-frequency amplifiers which has a much better selectivity characteristic over the broadcast-frequency range than systems used at present.

This result I accomplish by so proportioning the inductance and distributed capacity of the primary of each inter-tube, radio-frequency transformer that it has a natural period considerably below the lowest frequency to which the secondary is intended to be tuned. In addition, I may so relatively arrange the primary and secondary inductors that, at high frequencies, the inductive transfer of energy therebetween is reinforced by energy transferred through the capacity existing between such inductors by reason of their space relationship.

The novel features which I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof will best be understood by reference to the following description, taken in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic view of a preferred form of my invention incorporated into a multi-stage radio-frequency amplifying system,

Fig. 2 is a sectional view of a preferred form of inter-tube transformer,

Fig. 3 is a diagram illustrating graphically the difference between the voltage amplification characteristics of my improved coupling system and systems of the prior art,

Fig. 4 is a diagram showing curves illustrative of the selectivity characteristics of the usual low-inductance primary radio-frequency transformer, and

Fig. 5 is a diagram showing curves illustrative of the selectivity characteristics of my improved transformer.

Referring specifically to Fig. 1, a thermionic device having a filament 2, a grid 3 and a plate 4, is provided with an input circuit comprising an inductor 5 shunted by a tuning condenser 6. The inductor 5 may be a loop, or it may be a coupling inductor of any well known type, associated with an antenna-ground circuit (not shown). One end of the inductor 5 is connected to the grid by a conductor 7; a conductor 8 leads from an intermediate portion of the inductor 5 through a grid biasing battery 9 to the filament 2, and the opposite end is connected to the plate 4 through a small variable or fixed condenser 11. The purpose of the intermediate tap and neutralizing condenser, in radio-frequency amplifiers of the usual type, is to prevent the generation of self-oscillations in the tube and accompanying circuit network, as is explained in the Rice Patent No. 1,334,118. In my system, however, the condenser 11 has a somewhat different function, which will be later explained.

An inductor 12, which is the primary of a radio-frequency transformer 13, is connected between the plate 4 and the filament 2, a battery 14 supplying plate potential. A battery 15 in series with a rheostat 16 supplies filament power, and the same battery also may be utilized to energize the filaments of other tubes in the system, as indicated in the drawings.

A second thermionic device 18 having a filament 19, a grid 21 and a plate 22, has its grid 21 connected to one end of the secondary 23 of the radio-frequency transformer 13, and its plate 22 connected to the other end thereof through a variable or fixed condenser 24. A condenser 25 is connected across the inductor 23 in order that it may be tuned to a desired frequency, and a conductor 26 leads from an intermediate point thereon, through a grid-biasing battery 27, to the filament 19.

Plate potential for the thermionic device is supplied from the battery 14, the primary 28 of a radio-frequency transformer 29 being connected between the battery and the plate. The secondary 31 of the transformer 29 is shunted by a tuning condenser 32 and is connected to the remaining portion of the system by conductors 33 and 34.

The two tuned radio-frequency amplifying stages may be followed by additional radio-frequency stages, or by a detector and audio-frequency amplifier. The additional apparatus is optional, and, since it may follow conventional lines, if desirable, is merely indicated by a rectangle 35.

In order that the inter-tube transformers be sufficiently selective to reasonably eliminate interfering frequencies, it is only necessary that the ratio of reactance to radio-frequency resistance of the secondary be made at least so high that primary frequencies five kilocycles on each side of resonance do not induce currents of more than 80% of the resonance value in the secondary.

With the usual radio-frequency transformers, having low-inductance primaries, the approach toward resonance conditions in the primary at the higher frequencies effectively adds resistance to the secondary at such frequencies. Inasmuch as the radio-frequency resistance of the secondary is also higher at high than at low frequencies, it is seen that the total damping at high frequencies is considerably greater than it is toward the low-frequency end of the scale, and the selectivity is consequently poorer.

The results of a large number of tests on radio-frequency transformers of the usual type are summarized by the curves in Fig. 4. Curve C represents the voltage across the secondary tuned to 600 kilocycles, with varying input frequencies, and it is significant to note that a frequency five kilocycles away from resonance gives but 50% of the resonance voltage. Curve D illustrates the fact that the high-frequency end of the range in the usual transformer is much less selective than at the low-frequency end, frequencies five kilocycles away from resonance at 1450 kilocycles giving approximately 95% of the resonance voltage.

In order, therefore, to improve the selectivity at high frequencies, it is necessary to greatly reduce the losses at such frequencies. These losses may be reduced, according to my invention, by giving to the primary a resonance frequency such that it cannot be near resonance at the high frequencies. This may be accomplished by either greatly increasing or greatly decreasing the resonance frequency of the primary with respect to highest frequency to which the secondary is tunable. If, however, the resonance frequency of the primary is increased by lowering its inductance, the amplification at the low frequencies is poor.

Therefore, I preferably lower the resonance frequency of the primary to a point near or below the lowest frequency to which the secondary is tunable. Such a primary does not increase the effective resistance of the secondary at high frequencies but does increase the effective resistance thereof at low frequencies. The effective resistance thus introduced compensates the decreased damping resulting from the decreased radio-frequency resistance of the secondary at lower frequencies and broadens the tuning at such frequencies.

Curves E and F, in Fig. 5, summarize the results of a large number of tests made on my improved transformer. It will be noted from these curves that the selectivity at both the high-frequency end and the low-frequency end of the range is substantially the same, the relative displacement between the two curves never becoming greater than one tenth of the maximum resonant voltage.

By properly choosing the inductance and distributed capacity of the primary, and by carefully adjusting the mutual inductance of the primary and secondary, I am thus able to construct a transformer that will be satisfactorily selective at both the high and low-frequency ends of the tuning range.

In order to cover the present broad-cast-frequency range, I have found that a transformer having a primary inductance of approximately 5000 micro-henries and having a natural period of approximately 400 kilocycles, when in circuit, coupled with a secondary inductance of 175 micro-henries, is quite satisfactory. When using a transformer of these dimensions, the tuning condenser shunting the secondary should have a maximum capacity of 550 micro-microfarads and a minimum capacity of 15–20 micro-microfarads or less.

Referring particularly to Fig. 2, my preferred transformer comprises a primary 40 of 250 turns of #30 double-cotton-covered wire, in the form of a duo-lateral coil, and a secondary 41 of 72 turns of #24 double-cotton-covered wire wound as a single-layer solenoid. The inside diameter of both primary and secondary is two inches and they are preferably separated ⅜ths to ½ inches axially.

The curve "A" in Fig. 3 illustrates graphically the voltage-amplification characteristics of a transformer constructed according to my invention, while the curve "B" illustrates the characteristics of a transformer having the usual low-inductance primary.

According to my invention, therefore, higher-voltage amplification may be obtained at the lower frequencies than with transformers having primaries of relatively low inductance. This condition is considered desirable, inasmuch as the better broadcasting stations are, at present, operating at frequencies toward the lower end of the broadcasting range.

An amplifying system constructed according to my invention is relatively stable. At the higher frequencies, the reactance of the high-inductance primaries in the plate circuits of the tubes is predominately capacitive and, consequently, the conditions for negative feed-back are present. In order, therefore, that the system shall amplify efficiently, a certain amount of positive feed-back should be supplied and this feed-back is most conveniently introduced by utilizing a small condenser between the plate electrode and one end of the inductor associated with the grid of the same tube.

As already mentioned, the action of this arrangement is different from that of the Rice Patent 1,334,118, although diagrammatically they are similar in appearance. In the Rice Patent, the neutralizing condenser and that portion of the grid inductor included between the connection from the filament and the connection to the condenser cooperate to place, on the grid of the tube, potentials equal and opposite in phase to potentials placed thereon by reason of the tube-capacity coupling between the input and the output circuits in order that regenerative feed-back shall be compensated. In my invention on the other hand the normal reactance of the plate circuit is capacitive, tending toward "de-generation", instead of toward regeneration and oscillation, and the condenser 11 in combination with the portion of the winding with which it is connected, act to produce a regenerative feed-back. While, therefore, the circuit arrangement is diagrammatically like that of the Rice patent, the effect of the condenser and its associated coil is regenerative after the well known Weagant regenerative circuit.

Although not specifically shown in the drawings, it is believed obvious that my invention may be applied to systems in which the plate or output coil for each stage is inductively associated with another coil that is comprised in a feed-back system. The feed-back coil may be a continuation of the output coil itself, in which case the said output coil could be characterized as "split".

I have found, in addition, that the necessary amount of positive feed-back may be supplied by utilizing certain other well known feed-back systems, in which either capacitive or inductive back-coupling, or a combination of the two, is depended upon.

It is possible to arrange the relative direction of the transformer winding, as indicated in Fig. 1, in order that the coupling between the primary and secondary, by reason of the inter-winding capacity, may assist, in proper phase, the transfer of energy electromagnetically from the winding to the other.

The capacity coupling may be greatly increased by placing the grid and plate ends of the respective windings so they are adjacent, provided the relative direction of the windings is such that the capacity coupling is in proper phase.

By varying the spacing between the primary and the secondary, the voltage-amplification characteristics of the transformer may be appreciably altered, inasmuch as there is a considerable transfer of energy at the higher frequencies across the inter-winding capacity. An optimum spacing can be determined for each transformer, the spacing 42 for the specific transformer illustrated in Fig. 2 being approximately ⅜ths inches.

By reversing the relative direction of the windings, the capacity coupling will then oppose the electromagnetic coupling, and the amplification at the higher frequencies will be considerably lessened.

I have accordingly provided a radio-frequency amplification system which has a substantially straight-line selectivity-characteristic over the range of frequencies for which it is designed. My improved coupling system may also be given an approximately straight-line voltage-amplification characteristic, although it is somewhat preferable to have a higher voltage step-up at the lower frequencies.

My improved system is also remarkably free from parasitic oscillations, and, although preferably utilizing a feed-back means analogous to the usual neutralizing condenser and associated network, such means is not primarily for the purpose of neutralizing the system against oscillations.

Although I have illustrated and described only one specific embodiment of my invention, it is believed obvious that numerous modifications will be apparent to those skilled in the art. My invention, therefore, is not to be limited except in so far as is necessitated by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. In a tunable radio-frequency amplification system, a plurality of thermionic devices, coupling means therebetween so designed that the system has an approximately straight-line selectivity characteristic, said coupling means comprising a transformer having a primary with a natural frequency low in comparison with the mid-range frequency of the system and feed-back means for improving the response of the system to high frequencies.

2. In a radio-frequency amplification system, a plurality of thermionic devices, and coupling means between two of said devices comprising a transformer having a secondary in the form of a single layer solenoid, and a primary in the form of a multi-layer coil which is resonant at a frequency outside of the band of frequencies within which said amplification system is designed to function.

3. A radio-frequency amplification system comprising a plurality of thermionic devices, coupling means therebetween comprising a primary of such a value of inductance that the predominant reactance thereof at high frequencies is capacitive, and means for balancing the negative feed-back caused by such reactance.

4. In a radio-frequency amplification system, a plurality of thermionic devices, coupling means between two of said devices comprising a transformer having a primary winding the natural period of which is lower than the lowest frequency the system is intended to amplify, a secondary winding, means for tuning said secondary winding and means for transferring energy from the output circuit that includes the primary winding to the input circuit of the device to which said output circuit pertains.

5. In a radio-frequency amplification system comprising a plurality of thermionic devices, coupling means therebetween comprising a primary winding of such value of inductance that the predominant reactance thereof at high frequencies is capacitive, means for balancing the negative feed-back caused by such reactance, and a tunable secondary winding.

6. In a radio-frequency amplificaton system, a plurality of thermionic devices, coupling means between certain of said devices for inductive and capacitative transfer of energy therebetween in aiding sense and additional means for transferring energy from the output to the input circuit of one of said devices.

7. In a radio-frequency amplification system, a plurality of thermionic devices, coupling means between certain of said devices for inductive and capacitative transfer of energy therebetween in aiding sense, said means being constituted by a primary winding having high distributed capacity and a tunable secondary winding, and means for transferring energy from the output circuit to the input circuit of one of said devices in the sense to promote regeneration.

8. In a radio-frequency amplification system, a plurality of thermionic devices, coupling means therebetween consisting of a multi-turn primary winding having large distributed capacity disposed in inductive and capacitative relation to a tunable secondary winding, said secondary winding being so connected to the input terminals of one of said thermionic devices that the energy transferred between said devices through inductive and capacitative coupling is in aiding sense.

9. In a radio-frequency amplification system comprising a plurality of thermionic devices, coupling means between adjacent devices comprising a primary winding of such a value of inductance that the predominant reactance thereof at high frequencies is capacitive, and a tunable secondary winding, the coupling between said primary and secondary windings being such that the effective resistance of the tunable secondary is greater at the lower frequencies in the tuning range of the said secondary than it would be if the reactance of the primary at high frequencies were predominantly inductive, whereby the effective resistance of the secondary is substantially constant over the tuning range thereof and the selectivity of the system is substantially uniform.

10. A tuned radio frequency amplifier having an input circuit and having an output circuit whose reactance is condensive, said output circuit delivering power to a tuned circuit, and means for feeding back power to the input circuit so as to eliminate the damping effect on said input circuit of the capacity reactance of said output circuit.

11. In combination, an output circuit of an electron discharge device whose reactance is negative, the output circuit feeding power to a tuned secondary circuit, a feed back coil and current limiting condenser connected in series between the anode and cathode of the electron discharge device, said feed back coil being magnetically coupled to the input circuit of the device.

12. In an amplifier, a thermionic tube, a tunable input circuit therefor, an output circuit therefor including a coil whose inductance is so great that the output current of the tube tends to flow mostly through the natural capacity of the coil and other capacities shunting said coil, causing a damping effect on the input circuit of said tube, and means including a path between the output and input circuits for counteracting said damping effect.

13. In an amplifier, a thermionic tube, a tunable input circuit therefor, an output circuit therefor comprising a coil whose inductance is so great that the output current of the tube tends to flow through the natural capacity of the coil causing a damping effect on the input circuit of said tube, and means for counteracting said damping effect, said means comprising an inductance and a condenser in series, said last mentioned inductance being magnetically coupled to the input circuit of said tube.

14. The method of operating a space discharge tube amplifier having an output circuit with a negative reactance which consists in feeding back energy from the output circuit to the tube input circuit through a path other than the inter-electrode coupling of the tube, to counteract the effect of said negative reactance on the input circuit.

15. The method of operating a multi-electrode amplifier tube having an output circuit which exercises a damping effect upon the tube input circuit, the method consisting in establishing a path between the output and input circuits other than through the tube electrodes, and feeding energy from the output to the input circuit along the said path so as to counteract said damping effect.

16. The method of operating an amplifier circuit which includes a multi-electrode space discharge tube having an output circuit including a reactance naturally resonant to a frequency below the broadcast range and which exercises a damping effect on the tube input circuit, the method consisting in regeneratively coupling the output circuit to the input circuit, and feeding back energy from the output to the input circuit to counteract said damping effect.

17. A tuned radio frequency amplifier having an input circuit and an output circuit, the latter having a negative reactance, and exercising a damping effect on the input circuit, and a path between the output and input circuit for feeding back energy to the latter to eliminate said damping effect, said path including an adjustable reactance.

18. In an amplifier, a space discharge device, an input circuit therefor, an output circuit therefor including a reactance which exercises a damping effect on the said input circuit, and a path including a pair of reactances between the output and input circuits for counteracting said damping effect, one of said reactances being variable.

19. In an amplifier, a spaced discharge tube including a tunable input circuit and an output circuit, a coil in said output circuit naturally resonant to a frequency outside a

predetermined frequency range and causing a degenerative effect on said input circuit, and a path between the output and input circuits for counteracting said effect.

In testimony whereof, I have hereunto subscribed my name this 18th day of November 1926.

GEORGE L. BEERS.