Sept. 4, 1928.

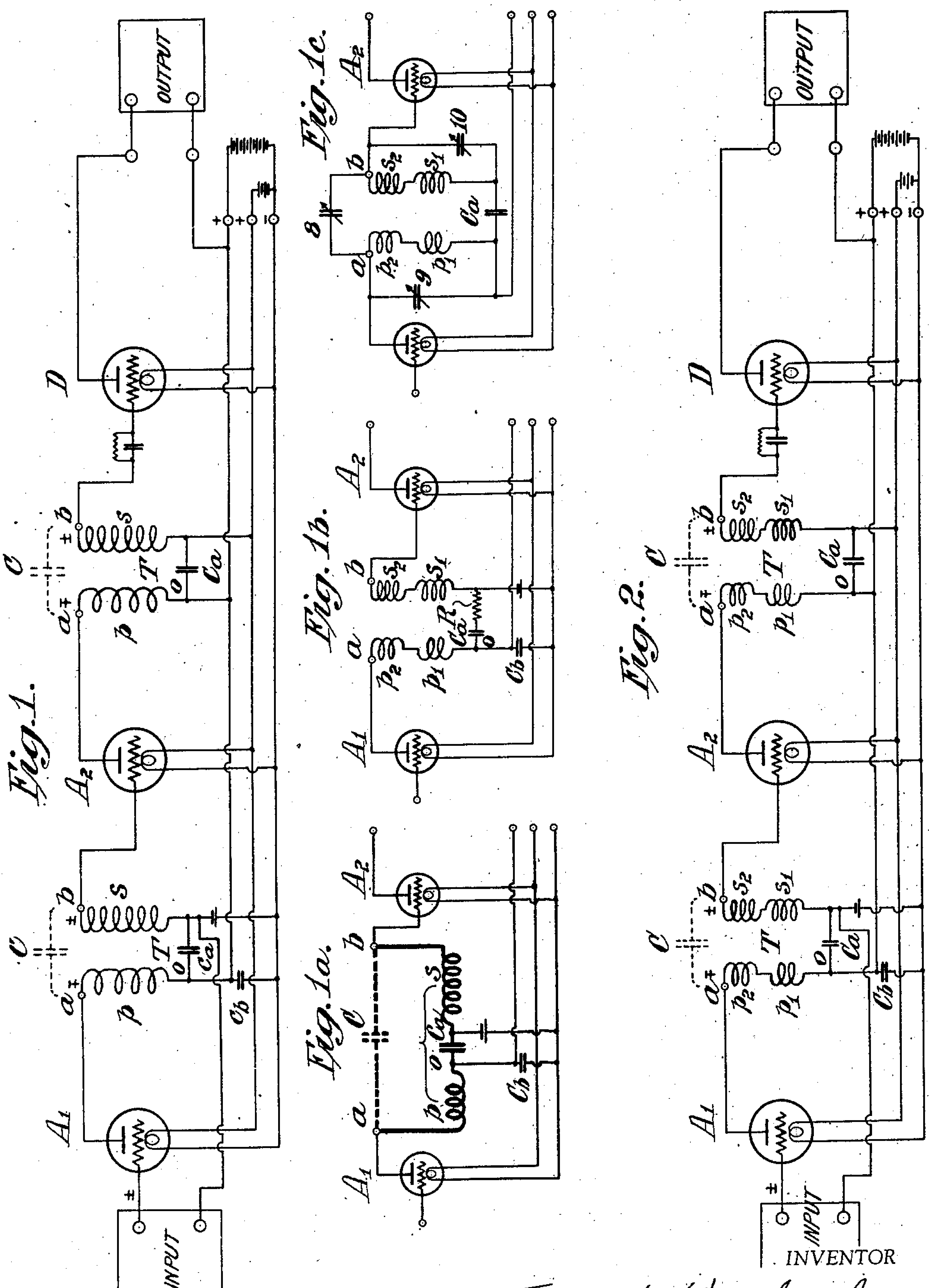
F. K. VREELAND

1,682,874

RADIO FREQUENCY AMPLIFIER

Filed Aug. 6, 1923

3 Sheets-Sheet 1



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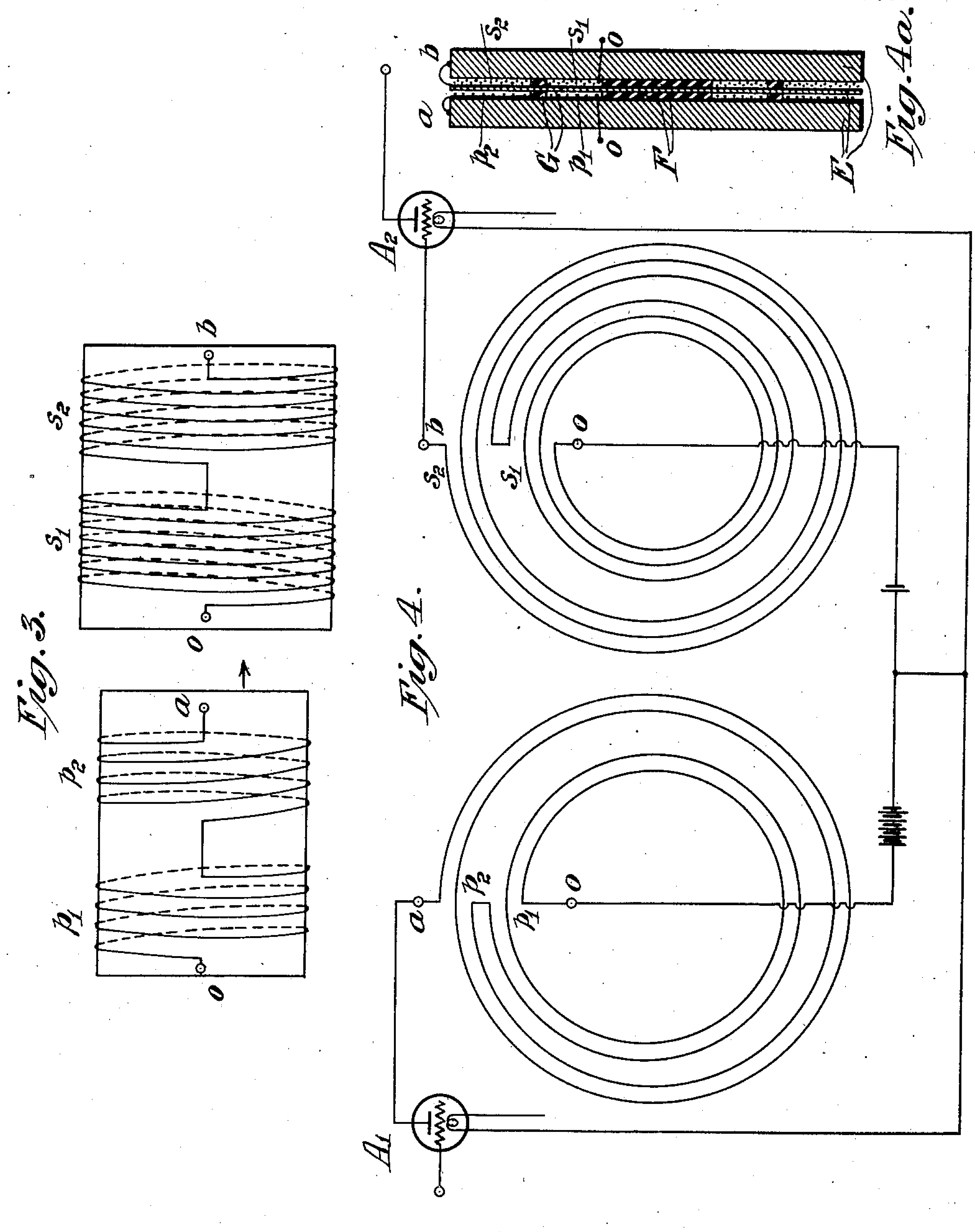

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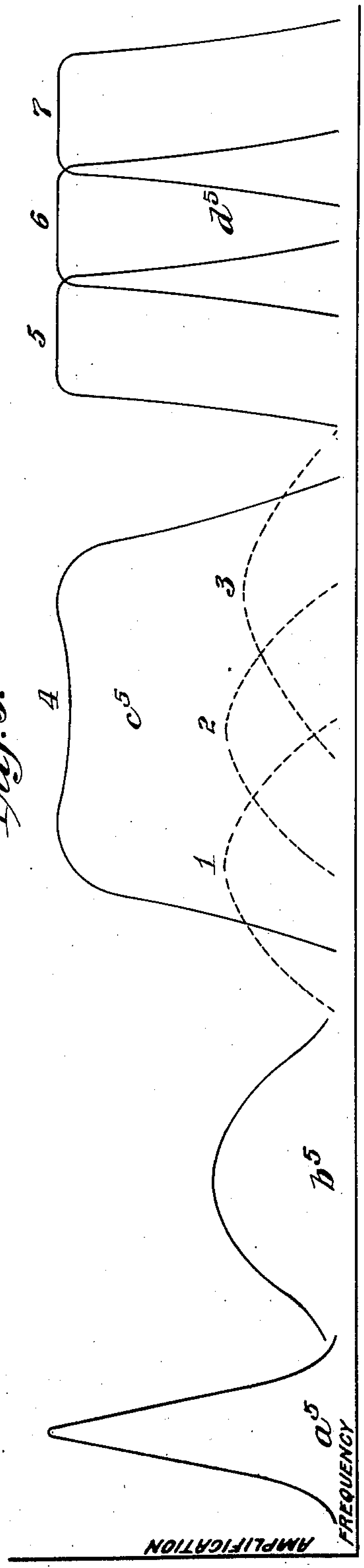

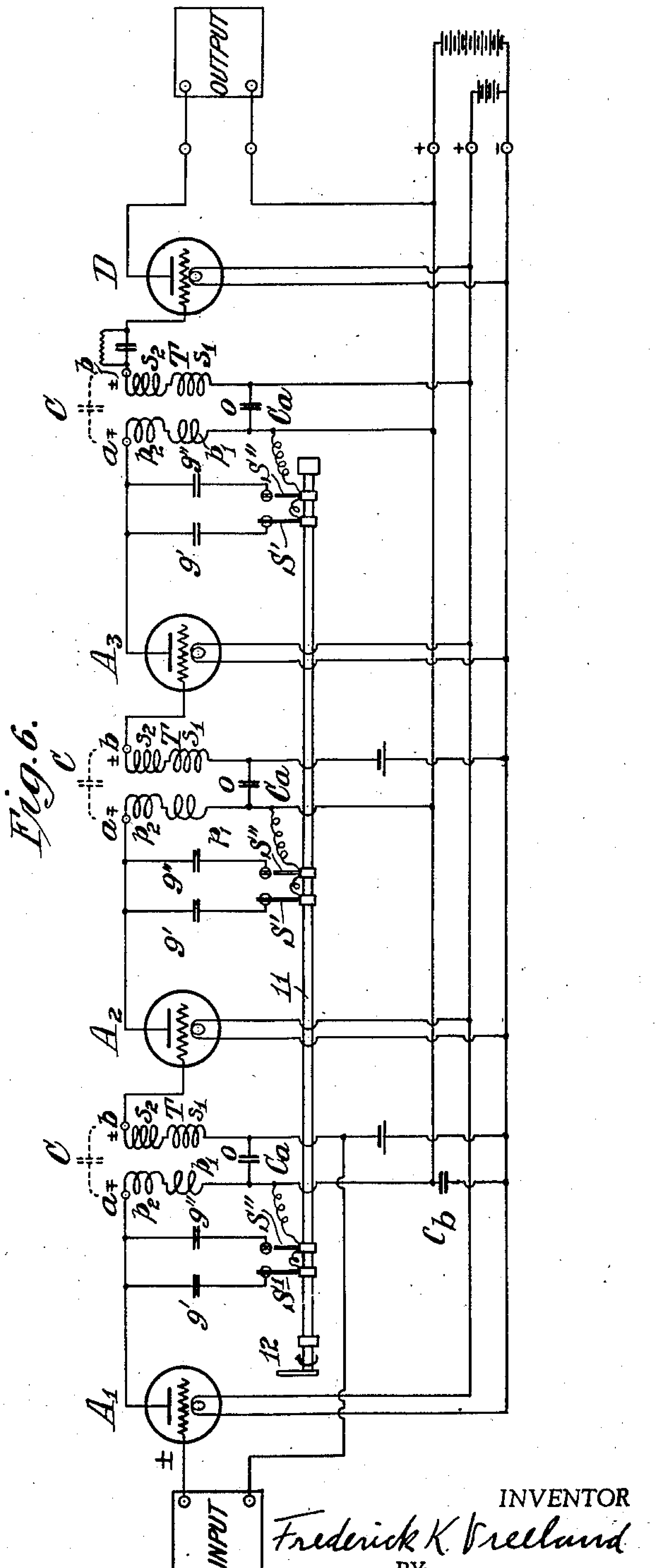

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UNITED STATES PATENT OFFICE.

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RADIO FREQUENCY AMPLIFIER.

Application filed August 6, 1923. Serial No. 655,794.

The invention herein described relates to amplifiers for high or radio frequency currents and is particularly concerned with devices for coupling amplifier tubes in cascade. It has for one of its objects the elimination or minimizing of the effects of detrimental capacity and stray fields, and the production of an amplifier of greatly improved efficiency.

In my U. S. Patent No. 1,666,518, issued upon a division of the present application, are described and claimed certain forms of apparatus adapted for the practice of the method to which the present claims of this application are particularly directed, to wit, the method of accomplishing band amplification and specifically to the control of the band characteristic, including features whereby the amplification is made effective or substantially uniform for all frequencies within a given band or range, while frequencies outside this band are almost completely excluded. In accordance with one phase of the invention reactances, or specifically capacities are added in successive stages of amplification and such reactances or capacities are adjusted or changed for the purpose of altering the frequency characteristic of the amplifier and particularly for shifting the position of the band over which it operates in the frequency scale. In accordance with another phase of the invention the polarity of the amplified output is reversed for the purpose of establishing a phase relation of the currents in the several stages of amplification which minimizes the tendency to regeneration and oscillation.

In the drawing Fig. 1 is a schematic diagram showing a simple form of apparatus embodying the invention. Figs. 1^a, 1^b and 1^c show alternative arrangements of certain features of Figs. 1, 2 and 6.

Fig. 2 is a modified form in which the astatic feature is included.

Fig. 3 is a more detailed diagram showing the physical construction of one type of coupling transformer.

Figs. 4 and 4^a show the structural features of another type of transformer embodying the invention.

Fig. 5 shows the amplification characteristics secured by application of the invention.

Fig. 6 is a schematic diagram of a multiple band amplifier.

One of the most serious limitations in the design of radio frequency transformers, as usually practiced, is the fact that the secondary electromotive force is largely dissipated in stray capacities, so that only a fraction, and sometimes a small fraction of it is useful in producing amplification. Usually it is considered impracticable to construct such a transformer having a step-up ratio, because the electromotive force gained by the step-up ratio is frittered away in these stray capacities, including the capacity of the transformer itself.

By means of the present invention I not only avoid the detrimental effect of capacity in the windings, but I utilize the capacity to produce an improved result. By means of this invention I am enabled to construct a transformer of high efficiency with a step-up ratio.

Another difficulty in radio frequency amplifiers of the usual type is inter-action of the various stages, when amplifiers are used in cascade, which reduces the effective amplification and tends to instability or oscillation of the system. An important feature of the present invention is an arrangement of windings whereby the external field of the transformer is reduced to a minimum so that it becomes practically astatic and inductive disturbances are eliminated.

A particular feature of the present invention resides in performing the amplification in successive stages having different amplication-frequency characteristics, which are preferably spaced in the frequency scale with an overlap so related to the width of the characteristics that the combined amplifying effect of the system is substantially uniform for a given band of frequencies. The specific feature relates to the shifting of this band in the frequency scale while preserving its band character.

In the drawing Fig. 1 shows schematically a simple embodiment of the invention, as applied to a radio frequency amplifier of three tubes. In the arrangement shown, two of the tubes A_1, A_2 are used for radio frequency amplification and the third D as a detector. When in the following I refer to amplifier tubes generically it will be understood that one of these may be used for detection as shown. TT are transformers coupling the tubes in cascade, each including a primary coil p and a secondary coil *s*. In the first transformer the outer terminal of the primary coil *p* is connected to the output terminal or anode of the first amplifier tube A_1 and the outer terminal of the secondary *s* is connected to the input terminal or grid of the second amplifier tube A_2. The second transformer is similarly connected to the second amplifier tube A_2 and the detector tube D. The primary and secondary coils are wound or connected in opposite senses so that their outer terminals *a* and *b* respectively are at opposite potentials, instead of being at like potentials as is usual in the construction of such transformers. This feature is indicated in the diagram by the sign $\mp$ on the primary terminal *a*, and $\pm$ on the secondary terminal *b*, indicating that the polarities of these terminals change in opposite senses. The resulting potential difference between these terminals, which would ordinarily be detrimental, is utilized to assist instead of opposing the magnetic coupling. Thus the transformer may be so constructed that the primary and secondary windings constitute in effect a condenser, whose capacity augments or assists the magnetic coupling effect of the windings, as will be explained. This inherent capacity of the windings is indicated by the dotted capacity couplings C in the drawings, dotted lines being employed to indicate that the capacities, although physically and necessarily existant as capacities, do not necessarily require separate structural elements, as usually employed, but may be inherent in the transformer structure. If desired an external condenser may be connected across the terminals *a b* to augment the inherent capacity of the transformer windings as shown at 8 in Fig. 1^c.

This capacity, whether inherent in the windings or external, assists the magnetic coupling of the transformer. It may be so chosen that its effective reactance at the preferred operating frequency is approximately equal to the combined reactances of the coils *ps*, so that the transformer becomes in effect an oscillating circuit *ps*C, tuned approximately to the operating frequency, due allowance being made for the capacities of the associated tubes when these are material with respect to the capacity of the transformer. The result of this arrangement is that the full potential difference between the terminals *a b* is effective in coupling the output of one tube with the input of the next.

The windings *ps* may be similar, in which case the useful secondary potential will be much larger than that of an equal ratio transformer not embodying this invention, but preferably the secondary is made with more turns than the primary so that a step-up ratio is secured.

The significance of this arrangement will be seen more clearly by reference to Fig. 1^a, which is a simplified schematic diagram showing the relations of one pair of tubes to the coupling system. The inductance of the coupling system comprises the inductance of the primary coil *p* and that of the secondary coil *s*, together with their mutual inductance, and the capacity C is the inherent or the total capacity of the system. The oscillating system *ps*C is tapped at three points, *a*, *b*, and *o*, point *o* being the negative bus or neutral point. The input electromotive force is applied between *a* and *o*, and the output electromotive force is taken off between points *b* and *o*. The ratio between the input and output electromotive forces is determined by the inductive drops across coils *p* and *s*, which may be given any desired value within wide practical limits by suitably proportioning the coils.

To secure the best results it is usually desirable to shunt the external connections of the transformers including batteries, resistances, etc., by bridging condensers such as c_a whose capacity reactance in the working range of frequency is small. These serve to by-pass the high frequency oscillations across the inner terminals of the transformers, avoiding external loss by completing the closed circuit including the windings *ps* and the mutual capacity of the coils by the shortest possible route. Other bridging condensers such as c_b may be used when desired to bypass the output current of one tube and the input current of the next to the filament or ground bus.

Fig. 2 shows an improved arrangement which includes the features contained in Fig. 1 and has in addition an astatic feature whereby the external field of the transformer is practically eliminated. In this arrangement each of the coils of the transformer is made in two sections, wound or connected in opposite directions so that their external fields oppose and neutralize each other. In the primary the two sections are p_1p_2 and in the secondary the two sections are s_1s_2. The section p_1 is arranged preferably in close inductive relation with the section s_1 and the section p_2 in close inductive relation with the section s_2, so that a relatively close coupling is obtained between primary and secondary through their unbalanced internal fields, notwithstanding the opposing relations of the two halves of these windings which cause their external fields to balance and neutralize each other. The sections p_1s_1 are wound or connected in opposite senses, as explained in connection with Fig 1, and the same is true of the sections p_2s_2, so that the external terminals *a b* will have opposite polarities as in the arrangement of Fig. 1. The physical dimensions and relative positions of the coils may be so chosen, as in the case of Fig. 1, that the effective capacity between the terminals a b has a reactance at the preferred operating frequency approximately equal to the inductance reactance, so that at this preferred frequency the maximum effective potential difference is obtained between terminals a b.

In this arrangement it will be noted that while the mutual induction of the two windings is relatively large, their external magnetic field is negligible. Since the potentials of the terminals a b are opposite, the stray electrostatic fields are also reduced to a minimum so that undesired couplings are practically eliminated. This arrangement of windings also offsets the reversal of polarity occurring in the amplifier tube, so that all tubes have like polarities, and the tendency to regeneration or oscillation by mutual interaction is avoided.

There are various forms of construction that can be used in carrying out the invention. One of these is shown in Fig. 3, in which cylindrical or solenoidal windings are used. Here the primary coil is made in two halves, p_1p_2, wound in opposite directions as shown, and the secondary coil is also wound in two opposing halves s_1s_2 as indicated. The primary and secondary coils are shown separated for clearness of illustration of the windings. In operation the primary coil is placed inside the secondary, or vice versa, and the dimensions of the windings and diameters of the tubes are so chosen that the capacity between windings has the requisite value. The drawing shows also the direction of winding of the coils which gives the opposite potentials at the external terminals a b.

Figs. 4, and 4ª show another type of winding in which the coils are in disc form. These coils are wound preferably in slots of suitable thickness between three insulating discs E, clamped together with central spacers F forming a core on which the coils are wound. The slot for the secondary is preferably made wider than that of the primary so that the secondary has a larger number of turns. The coils are constructed by winding first the desired number of turns in one direction for the inner half of the coil, as p_1, then winding silk thread to form a spacer G and finally winding the second section of the coil p_2 in the opposite direction. The same construction is used in the secondary coil s_1 s_2, though in this case preferably the number of turns in each section is greater.

The dimensions of the coils and the distance between them are so chosen that the capacity has the desired value in relation to the inductance of the windings.

Either of the constructions shown in Figs. 3, 4 and 4ª may be used for the transformers TT in Figs. 2 and 6, or any other suitable construction, preferably embodying the features herein described, may be used, although the major features of the invention particularly claimed herein may be carried out with any suitable coupling means. Where coupling transformers are used as shown, a great variety of constructions may be employed, permitting the choice of any desired amplification frequency characteristic for the individual amplifier units and their coupling means, and so providing considerable latitude in the combined or overall band characteristic. Thus by winding the transformer coils with low resistance the apparatus may be made highly selective, so that the transformer circuit with its inherent and associated capacities is resonant to a definite frequency and the amplification is high for this frequency but lower for any other frequency. The individual characteristic curve of such an amplifier unit is shown at a^5 Fig. 5 in which the ordinates represent the ratio of amplification and the abscissas represent the frequency. On the other hand, where an amplifier is desired which works effectively over a wide range of frequencies I prefer to wind the transformer coils or particularly the secondary coil of relatively high resistance; for example by winding them of fine copper or larger German silver wire. This resistance has the effect of lowering the peak of the amplification curve without greatly lowering its amplitude at frequencies different from the peak frequency, so that a broad characteristic is secured without corresponding loss in efficiency, as shown for example in b^5 Fig. 5.

The degree of coupling between the coils is also an important factor in determining the characteristics of the several amplifier units. Where a broad characteristic is desired I prefer to make the coupling as close as practicable. Where a sharply selective characteristic is desired a looser coupling is permissible. By suitably proportioning the coupling and resistance, as well as the inductance and mutual capacity of the windings, the characteristics of the amplifier may be determined at will.

A substantially flat combined or overall characteristic may be obtained over a desired band of frequencies by the use of amplifier units in cascade having individual characteristics which are different. For example, Fig. 5, at c^5, shows a typical characteristic of a three stage band amplifier. The curves in broken lines 1, 2, 3 show the characteristics of the three individual units including tubes and transformers or other coupling means that are connected in cascade, while the full line curve 4 represents the resultant or overall band characteristic of the combined system.

The different characteristics of the individual units of a band amplifier may be determined by the design of the windings, or characteristics like those shown in 1, 2, 3 at c^5 in Fig. 5 may be obtained from transformers of identical windings by suitably choosing the distance between the coils and the resulting mutual capacity or by other suitable means.

A convenient means of adjusting the characteristic of a transformer at will is by the use of condensers. Three ways of doing this are shown in Fig. 1^c. The first is by shunting an external condenser 8 across the outer terminals of the primary and secondary coils p_1 p_2 s_1 s_2. This external capacity is in effect added to the inherent mutual capacity of the coils, and so lowers the frequency characteristic. The second arrangement consists in connecting a condenser 9 in parallel with the primary coil p_1 p_2. This has a result equivalent to increasing the effective inductance of the primary coil and consequently it lowers the frequency characteristic. A similar result is obtained by connecting a condenser 10 across the secondary coil s_1 s_2, but the effect of such capacity is proportionately greater than when the same capacity is added at 9 if, as I prefer, the transformer coils p_1 p_2 s_1 s_2 have a step-up ratio.

The condensers or capacities 8, 9, 10 may be used singly or in any desired combination, and any or all of them may be made variable. An effective arrangement for tuning the coupling transformers is secured by designing the transformer to have a sharply selective characteristic and inserting a variable condenser at 9.

A particularly useful modification of the band amplifier is shown in Fig. 6. Here are three transformers with their corresponding tubes arranged in cascade. These transformers are preferably designed to have overlapping characteristics as shown at c^5 in Fig. 5, giving a combined band characteristic which is flat. It will be observed from this figure that when the spacing of the individual characteristics is suitably related to the width or form of the characteristics, the resultant characteristic of over-all amplification is a substantially flat band with a sharp cut-off at each side. The desired spacing may be secured by any of the means herein described for determining the frequency characteristic of the amplifier, or by any other suitable means. This characteristic is shifted in the frequency coordinate by adding impedances to the transformer systems, preferably by the use of small condensers 9′ 9″ of suitably proportioned capacity so arranged that they may be shunted successively across the transformers. These condensers are cut in and out by switches S′ S″, the switches S′ S′ S′ being arranged to be operated simultaneously, for example by mounting them on a common rock shaft 11 operated by a handle or lever 12. Similarly the switches S″ S″ S″ operate simultaneously. When the switches S′ are closed by rocking the shaft, cutting in the condensers 9′, the characteristics of all the transformers are changed in frequency so that the combined characteristic is a flat topped band displaced in the frequency coordinate as shown at 6 in part d^5 Fig. 5. Additional condensers 9″ may be switched on by a further movement of the rock-shaft 11, closing the switches S″, and in this way the operating range of the amplifier may be broadened as far as desired. Preferably the capacities of the condensers 9′ 9″ are so chosen that the bands 5, 6, 7 have a slight overlap, as shown.

This arrangement has numerous advantages, particularly when used for selectively amplifying high frequency signal waves and eliminating interference. An amplifier is secured which gives practically uniform amplification over a wide range of frequencies, and the sub-division of this range into a plurality of narrower bands is useful in eliminating interference from signals of undesired frequencies, since the amplifier is highly effective for frequencies within its band but excludes almost completely frequencies outside of this band. By this means extremely feeble signals may be received without interference from the most powerful nearby stations.

While I prefer to shunt the band-shifting condensers 9′ 9″ across the primary coils p_1 p_2 as shown, they may be placed, if desired, in any of the positions 8, 9, 10, shown in Fig. 1^c. This feature is not specifically claimed in this application, but is specifically claimed in a separate application.

The flatness of the band of effective amplification and the sharpness of the cut-off for frequencies outside this band, which characterize the preferred form of my invention, are secured by so relating the spacing of the characteristics of the several amplifier stages to the width and form of the characteristics as to secure the particular overlap that is required for the characteristic employed. This relation is illustrated in Fig. 5, c^5, which shows curves for a three-stage amplifier.

Considering the relation of these curves at different frequencies, it is noted that for a frequency less than the peak frequency of the characteristic 1, characteristic 3 shows substantially no amplification and the over-all characteristic is small. As the frequency is increased, all the component characteristics are increasing simultaneously, and the amplification rises very sharply up to a frequency corresponding to the peak of curve 1. At this frequency curve 1 begins to fall while the others rise more slowly, and, by virtue of the particular spacing employed, the rise of one curve substantially offsets the fall of another, so that the amplification is substantially uniform, up to a point corresponding approximately to the peak of curve 3, beyond which all of the curves are descending. The resultant characteristic descends with a very sharp cut-off.

It will be noted that while all of the component characteristics are selective, their cut-off is gradual in the manner that is usual in resonance curves. In the case of the over-all band characteristic 4, however, the cut-off is sharp—much sharper than the slope of the component characteristics—so that the width of the curve at its base is not materially greater than that of the component characteristics, notwithstanding the breadth and flatness of the band at its top. This is of great importance since it permits a high degree of selectivity due to the sharp cut-off, notwithstanding the width of the band of effective amplification.

The flatness of the band depends upon the spacing. If the spacing is closer than the optimum, the over-all characteristic will be peaked, if the spacing is broader than the optimum, the over-all characteristic will have a central valley. Usually the optimum spacing is secured for a 3-stage amplifier when the high and low frequency characteristics (3 and 1, Fig. 5, c^5) intersect and overlap at a point corresponding to about half the maximum amplification. For other amplifiers the optimum spacing is readily determined by computation or graphic methods.

I claim as my invention:

1. The method of amplifying high frequency currents which consists in amplifying the current energy, inductively reversing the polarity of the amplified output, shunting the reversing inductance by a capacity whose reactance balances the reactance of the reversing inductance at a given frequency, and adding capacity to the system whereby its reactances are balanced at a different frequency.

2. The method of amplifying high frequency currents which consists in amplifying the current energy, inductively reversing the polarity of the amplified output, shunting the reversing inductance by a capacity whose reactance balances the reactance of the reversing inductance at a given frequency, and adding successive increments of capacity to the system whereby its reactances are balanced at successively different frequencies.

3. The method of amplifying high frequency currents which consists in performing successive stages of amplification having different amplification-frequency characteristics and in combination producing effective amplification over a given band of frequencies, shifting the frequency of this band while preserving its band character by adding increments of reactance to the several stages of amplification, receiving currents of a given frequency within the desired band, and excluding frequencies outside this band.

4. The method of amplifying high frequency currents which consists in performing successive stages of amplification having different amplification-frequency characteristics and in combination producing effective amplification over a given band of frequencies, shifting the frequency of this band while preserving its band character by adding increments of capacity to the several stages of amplification, receiving currents of a given frequency within the desired band, and excluding frequencies outside this band.

5. The method of selectively amplifying high frequency signal waves and eliminating interference which consists in performing successive stages of amplification having different frequency characteristics, and spacing the frequency characteristics of the successive stages in the frequency scale with an overlap so related to the width of the characteristics as to produce in combination a band of substantially uniform amplification with a sharp cut-off at frequencies outside the band.

6. The method of selectively amplifying high frequency currents which consists in performing successive stages of amplification having different selective characteritics, spacing the characteristics in the frequency scale with an overlap so related to the width of the characteristics as to produce effective amplification over a band of frequencies with a sharp cut-off at frequencies outside this band, and shifting the characteristics in the frequency scale while maintaining the spacing relation, thereby shifting the band of effective amplification in the frequency scalé while preserving its band character.

This specification signed this 31st day of July, A. D. 1923.

FREDERICK K. VREELAND.