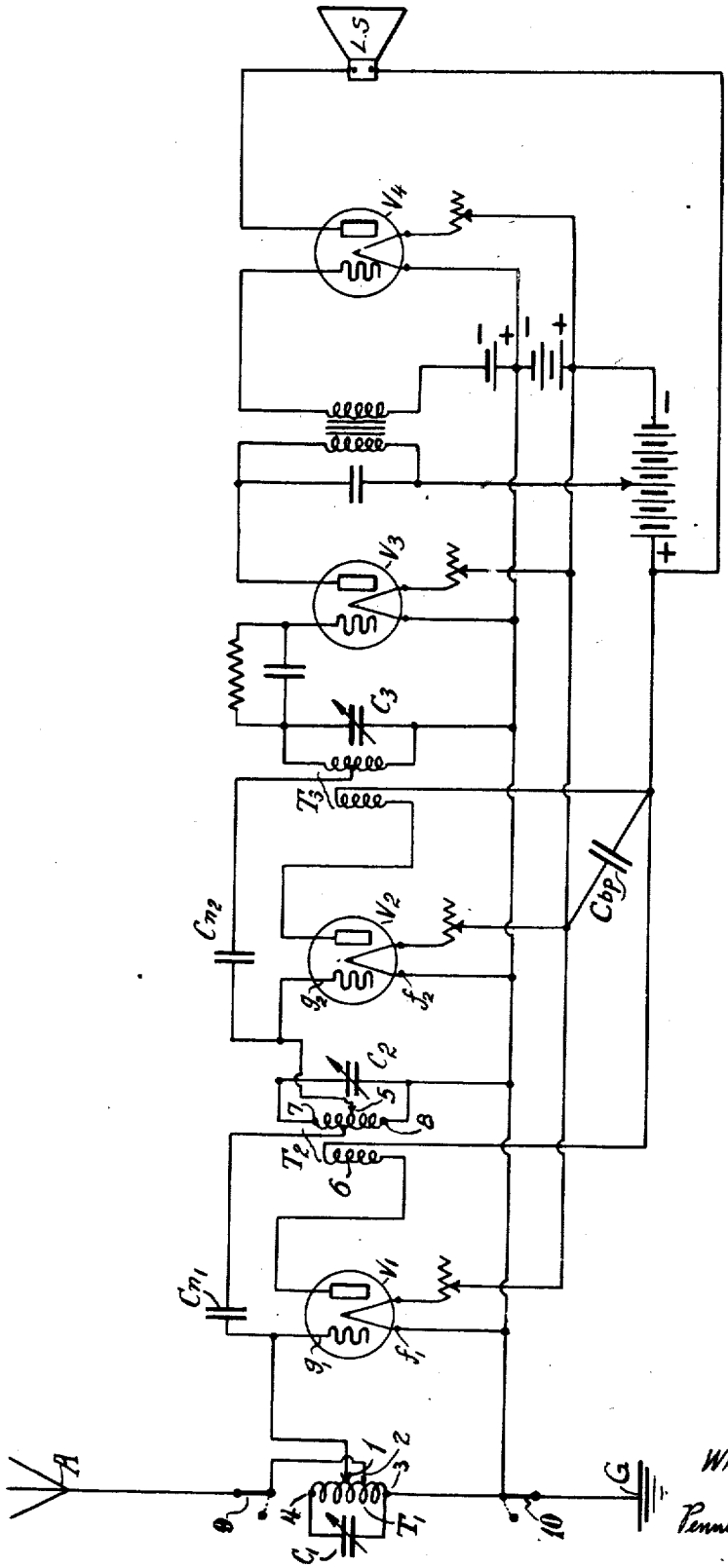
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W. A. MacDONALD

AMPLIFYING SYSTEM

Filed Feb. 3, 1926



INVENTOR

William A. MacDonald

BY

Pennie, Davis, Marvin & Edmonds

ATTORNEYS

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WILLIAM A. MacDONALD, OF LITTLE NECK, NEW YORK, ASSIGNOR TO HAZELTINE CORPORATION, OF JERSEY CITY, NEW JERSEY, A CORPORATION OF DELAWARE.

AMPLIFYING SYSTEM.

Application filed February 3, 1926. Serial No. 85,615.

This invention relates to amplifying systems, and especially to high-frequency amplifying systems wherein several vacuum tubes are connected in cascade, and coupled by means of highly efficient circuits.

The object of the invention resides in the provision of means for increasing the stability of such systems without sacrificing the desired amplification; and, concurrently, for effecting a more uniform voltage amplification characteristic throughout the operating frequency range of the system. To this end, the impedance of the input circuit of one or more of the amplifying tubes is reduced to a suitable value, while the average impedance of the preceding circuit coupled thereto is increased so as more nearly to equal the impedance of the circuit from which it derives its energy.

The present invention is especially applicable to radio receivers provided with means for neutralizing the undesirable capacitive coupling between the input and output circuits of the high-frequency amplifying tubes, such as the arrangement described in Hazeltine U. S. Patents Nos. 1,489,228 and 1,533,858. In the operation of radio receivers wherein highly efficient tuned circuits are employed with a view toward obtaining maximum high-frequency amplification per stage, it has been found that the tendency toward undesirable oscillations due to stray feedback couplings between portions of the various input and output circuits is especially noticeable. For example, the extremely small capacitive coupling existing between the detector input transformer and the antenna coil, while usually negligible in amplifiers utilizing one or two stages of high-frequency amplification of moderate magnitude, may be sufficient to cause undesirable oscillations, or tendency toward oscillations with accompanying signal distortion, in the case of amplifiers utilizing maximum amplification per stage, especially when three or more stages are employed. The filament system being common to the several tubes, a stray or undesirable coupling, either capacitive or electromagnetic, or both, between the input circuit of the first high-frequency amplifying tube of the series and some subsequent portion of the receiver, such as the input circuit of the detector tube, will cause a potential difference across the input-circuit impedance of the first high-frequency amplifying tube above-mentioned. Since the grid-filament electrodes of the first tube are also terminals of the input-circuit impedance, this potential difference will impress a voltage upon the grid of that tube, and hence the undesirable feed-back voltage thus impressed upon the grid of the first tube will be proportional to the value of impedance between the grid and filament terminals. This impedance will hereinafter be referred to as the "impedance of the grid circuit" or "input-circuit impedance". It is well understood in the art that in any given amplifying circuit arrangement including vacuum tubes, a certain amount of feed-back of energy can be tolerated before undesired oscillations are produced. However, for best results, it is preferable to eliminate substantially all undesired feed-back which tends toward instability even when such feed-back is of a degree insufficient to produce oscillations. Accordingly, it is the purpose of the present invention to provide a method and means whereby this "input-circuit impedance" of whatever tube in the series is thus undesirably effected, may be reduced to a value sufficiently low to substantially eliminate the undesired effects of feed-back voltage upon the grid of that tube without substantially reducing the effective desired voltage amplification of the system; and concurrently to realize a more uniform voltage amplification characteristic thruout the operating frequency range of the system.

Experimental measurement has shown that with the highly efficient tuned coupling transformers preferably employed in amplifying systems for broadcasting purposes, such as, for example, one having an operating frequency range of 3 to 1, i. e., 1500 kilocycles to 500 kilocycles, a voltage amplification characteristic of approximately to 1 to 2½ obtains when these transformers are employed in conjunction with a vacuum tube having a mutual conductance of about 1000 micromhos. Under such conditions, the voltage amplification at 1500 kilocycles may be approximately 16, with a gradually decreasing amplification gradient to 500 kilocycles. It is evident, therefore, that when two stages, similar to that just described, are connected in cascade, the amplification at 1500 kilocycles will be 16^2, or

256, while at 500 kilocycles the amplification will be 6.4^2 or 41. Accordingly, if three such stages are operated in cascade, the amplification will vary as the cube, and so on.

Similar conditions obtain in the input circuit of the first stage of a multistage amplifying system supplied with energy from an antenna, whether it be of the open type or of the loop type. In order to secure satisfactory selectively with such a system employing an open type antenna, it is usually desirable to include between the antenna and the input circuit of the first amplifying stage a step-up ratio of voltage transformation greater than 2 to 1. To attain this ratio, the untuned antenna coil which is coupled to the input circuit of the first high-frequency amplifying stage is usually composed of a small number of turns. This small inductance, together with the natural capacity of the usual antenna system employed in broadcast reception, provides a circuit resonant at a rather high fundamental frequency, and, under ordinary circumstances, such a circuit would likely be resonant at a frequency of approximately 1500 kilocycles, thereby providing maximum signal energy and amplification at that frequency, with a decreasing amplification gradient toward the lower frequencies.

The attainment of greater uniformity of amplification over the operating frequency range merely by increasing the secondary-to-primary transformer voltage ratio has heretofore been impracticable, because of the resulting high amplification, with its consequent tendency toward instability and oscillation. When the capacitive coupling between the input and output circuits of each tube has already been neutralized, such oscillations are generally caused by a feedback of energy between non-adjacent circuits, due to the stray capacitive or magnetic couplings between them. This tendency toward oscillation is increased, as previously explained, by the relatively high input impedance of the coupling transformers, which tends to force feed-back voltages through one or more of the vacuum tubes by impressing undesirable potential differences between the grid electrodes thereoef and the filament system.

This invention provides means for obtaining a greater uniformity of amplification throughout the operating frequency range of the amplifying system, while removing a principal cause of instability and undesirable oscillations. The invention may more readily be understood by a consideration of the following description of a preferred embodiment thereof as illustrated in the drawing, which shows a circuit diagram of a radio receiver including four vacuum tubes V_1 to V_4, inclusive; the first two being high-frequency amplifiers, the third a detector, or rectifier, and the fourth a low-, or audio-frequency amplifier. The capacitive coupling between the input and output circuits of vacuum tubes V_1 and V_2, respectively, is herein intended to be neutralized in accordance with the method described in the mentioned Hazeltine patents. For this purpose, neutralizing condensers C_{n1}, C_{n2}, are provided, each of which is connected from the grid of the tubes V_1 and V_2, respectively, to a suitable point on the secondary coil of the succeeding high-frequency amplifying transformers T_2 and T_3. The input circuits of tubes V_1, V_2 and V_3 are tuned by means of adjustable condensers C_1, C_2 and C_3. The usual filament current control rheostats are symbolically indicated, as are also suitable batteries for supplying operatitng potentials to the filaments, and to the plate and grid electrodes of the tubes. A loud speaker, or other low-frequency translating device, LS, is indicated as connected in the output circuit of the last low-frequency, or audio, amplifying tube V_4. A by-pass condenser C_{bp} is connected between the common terminals of the primary coils of coupling transformers T_2 and T_3, and the filament system, in order to provide a low-impedance path for the high-frequency return from output circuits to the filament system.

While the receiver illustrated includes but two high-frequency amplification stages, it should be understood that as many more such stages as necessary may be added; and, according to the preceding explanation, it will be plain that the present invention becomes of increasing importance as the number of high-frequency stages is increased. It should also be noted that as many stages of low-frequency amplification as desired may be employed in the well-known manner

The first high-frequency amplifying tube V_1 is coupled to the antenna system A, G by means of antenna-input circuit coupling coil T_1, which may, in the alternative, comprise a two-winding transformer. Coil T_1 is tuned by an adjustable condenser C_1, connected across its terminals. According to customary practice, this coupling coil would be connected to the grid g_1 of tube V_1 at the extreme terminal 4 of the coil. In like manner the grid connection g_2 of tube V_2 would be connected to the upper terminal 7 of the secondary coil of transformer T_2. However, it has been found, as explained above, that when such connection is made, the impedance of the coil between terminals 4 and 3 (or, in the case of transformer T_2, between the terminals 7 and 8) is usually sufficiently high to impress undesirable voltages of appreciable value upon the input circuit of the tube; such voltage being present because of stray capacitive or magnetic coupling between the input circuit of tube V_1 (or tube V_2) and some subsequent high-frequency circuit, such as the output circuit

V_2, the input circuit of V_3, or some portion of a succeeding high-frequency stage, in case more than two such stages are employed.

Because of the elusive character of such stray couplings, it is frequently impracticable to eliminate them, but the disadvantageous effects thereof may, in accordance with the present invention, be minimized by suitably reducing the impedance of the input circuit of the tube thus undesirably affected. In the case of tube V_1, the grid connection is tapped on to antenna-coupling inductance T_1 at some point substantially below the highest-potential terminal 4 of the coil. For the sake of simplicity, we may assume that this point is midway between the extremities of the coil, although in practice it is sometimes preferable to locate the tap elsewhere along its length. It follows, then, that the effective transfer of energy between one circuit (A, 2, 3, C) and the succeeding circuit (g_1, 1, 3, f_1) will be reduced. By thus placing the grid connection upon the midpoint 1, of the input inductance T_1, the impedance of the input circuit between the grid and the filament is reduced to approximately one-quarter of the value to be obtained by connecting the grid to the extreme terminal 4. This midpoint connection, of course, also reduces the desired voltage upon the grid of tube V_1 due to incoming signals, but this voltage is not reduced in proportion to the reduction of the impedance; measurements indicating that the signal voltage is thereby reduced a considerably smaller amount than is the impedance. In order to restore the signal voltage to a satisfactorily high value, the voltage across the input circuit inductance 1, 3 may be increased by locating the antenna tap 2 nearer the inductance terminal 4, at such a point that the required signal voltage is obtained upon the grid of tube V_1. It is clear that, once the proper number of primary turns is determined, the location of the tapped connection 2 may be made permanent for all other amplifiers similarly constructed. This increase in turns in the antenna inductance provides in addition the previously suggested advantage of decreasing the resonant frequency of the antenna circuit, the result being an increase in the amplification toward the low-frequency portion of the tuning range due to a nearer approach to resonance at that portion, thus improving the uniformity of the overall voltage amplification characteristic of the whole amplifier. In the event that a loop antenna is employed instead of the open antenna as illustrated, the tuning condenser C_1 would be connected across the extremities of the loop winding; the midpoint, or other intermediate point on the loop being connected directly to the grid g_1. If the switches 9 and 10 be opened, thus disconnecting the open antenna and ground, the inductance T_1 with its tuning condenser C_1 may be considered to represent a tuned loop antenna system. When used as a loop, the inductance T_1 would usually be physically larger than when employed as a coupling coil for an open antenna, as illustrated. In both cases, however, the circuit-diagram representation is the same.

The application of this invention to transformer T_2 introduces similar improvements in the second stage of amplification, where a similar process may be followed. For example, the connection from the grid lead g_2 may be placed at the midpoint 5 of the secondary winding 7, 8 of transformer T_2, thereby reducing the average grid-filament or input circuit impedance to about one-quarter of the value obtained by connecting the grid lead to terminal 7; and concurrently restoring and maintaining the desirable signal voltage upon the grid of tube V_2 by increasing the voltage across primary winding 6. This voltage increase may conveniently be obtained, as before, by increasing the number of turns included in the primary winding 6 to a suitable value. The increase in primary turns introduces the additional advantage of causing the average impedance of the primary circuit more nearly to equal the output circuit impedance of the preceding tube, namely V_1. As is well known in the art, such matching of impedances results in a more favorable voltage amplification ratio, as evidenced by the attainment herein of a nearly uniform voltage amplification over the operating frequency range of the system.

For the reason that in a system such as that described, the impedances can actually be matched at only one frequency, it is advantageous so to arrange the input and output circuits that the respective impedances are matched at that intermediate frequency of the entire operating frequency range of the system which will result in the particular voltage amplification characteristic desired. By way of example, the system herein described would approximate an horizontal voltage amplification characteristic if the impedances were matched at about 750 kilocycles.

The reduction of the input circuit impedance of the amplifying tubes, as effected by the present invention, introduces the further improvement of freedom from distortion, especially when no negative grid bias is used on the grids of the amplifying tubes, for the reason that when unusually large signal voltages are impressed upon the system, the low grid-filament circuit impedance tends to minimize wave-form distortion, with the incidental production of harmonic frequencies, commonly termed "overloading".

A further and especially advantageous im-

provement is introduced by the application of this invention to vacuum tube amplifiers whose effective grid-plate capacity has been neutralized, inasmuch as a greater tube capacity tolerance is thereby allowable; i. e., when the input-output circuit capacities in an amplifying system have once been neutralized or balanced to prevent undesirable oscillations, the same neutralizing adjustments may be retained even when there are substituted other vacuum tubes having somewhat different grid-plate capacities, without causing the system to become unstable.

The foregoing description of a single embodiment of the present invention necessarily concerns a particular form of radio apparatus, but it is to be understood that the principles described herein, and subsequently claimed, are intended to be applicable with equal force to any form of receiving or transmitting apparatus in which efficient high-frequency amplification is desired.

I claim:

1. In a multi-stage high-frequency vacuum tube amplifier system having coupling between two stages thereof whereby a tendency toward undesirable oscillation is produced in the tube of at least one stage of said system, the method of minimizing the effects of said coupling without substantially reducing the desired voltage amplification of the system, which comprises reducing all fluctuating voltages impressed upon the grid electrode of the tube thus undesirably affected, by reducing the impedance of the input circuit of that tube, and decreasing the step-up ratio between said input circuit and the output circuit of the vcauum tube next preceding, so that the desired signal voltage fluctuations upon said grid are maintained.

2. In a multistage high-frequency amplifier system including transformers coupling adjacent stages, each stage including a vacuum tube, undesirable coupling between the input circuit of the vacuum tube in one stage and a portion of a succeeding stage whereby undesirable feed-back voltage is impressed upon the grid electrode of said last-mentioned vacuum tube, a tuning condenser connected across the extremities of the secondary winding of a coupling transformer included in said input circuit, and a connection from the grid electrode of said vacuum tube to a tap intermediate the extremities of said secondary winding, whereby the feed-back voltage impressed upon said grid is reduced in greater proportion than the signal voltage.

3. In a tuned multi-stage high-frequency amplifying signaling system, each stage including a vacuum tube and a coupling transformer comprising a primary winding and a secondary winding, said secondary winding having a certain maximum inductance value and being tunable over an operating frequency band, said system having coupling between two stages thereof whereby a tendency toward undesired oscillation is produced by the tube in whose input circuit said secondary winding is connected, the method of minimizing the effects of said coupling without substantially reducing the desired signal voltage amplification of the system which comprises connecting substantially less than the maximum inductance value of said secondary winding in said input circuit whereby the input circuit impedance is decreased, and increasing the impedance of said primary winding to approximately match the impedance of the circuit in which it is connected, whereby the normal value of signal voltage impressed upon the grid of said last-mentioned tube is substantially restored.

4. In a multi-stage high-frequency amplifier system including transformers coupling adjacent stages, each stage including a vacuum tube, undesirable coupling between the input circuit of the vacuum tube in one stage and a portion of a succeeding stage whereby undesirable feed-back voltage is impressed upon the grid electrode of said last-mentioned vacuum tube, a tuning condenser connected across the extremities of the secondary winding of a coupling transformer included in said input circuit, the primary winding of said transformer being connected in the output circuit of a preceding vacuum tube, and a connection from the grid electrode of said vacuum tube to a tap intermediate the extremities of said secondary winding whereby the feed-back voltage impressed upon said grid is reduced in greater proportion than the signal voltage.

5. In a radio receiving system including an antenna system, a multi-stage high-frequency vacuum tube amplifier, one stage of which is linked with said antenna system by means of a coupling device comprising a primary winding connected in the antenna system and a secondary winding connected in the input circuit of said stage, whereby signal voltages are impressed upon the grid electrode of the vacuum tube of said stage, undesirable coupling between the input circuit of the vacuum tube in said stage and a portion of a succeeding stage whereby undesirable feed-back voltages are impressed upon the grid electrode of the vacuum tube of said stage, capacity means connected across said secondary winding for tuning the same to the frequency of said signal voltages within an operating frequency band, said primary winding having an inductance value such that the natural period of said antenna system is of a frequency less than the maximum frequency of said band and greater than an intermediate frequency of said band, and a connection from said grid

to a tap on said secondary winding intermediate the ends thereof whereby the impedance of said input circuit is limited to a value less than the total impedance of said secondary winding so that said feed-back voltages are reduced in greater proportion than said signal voltages.

6. In a radio signaling system, a multi-stage high-frequency amplifier including transformers coupling adjacent stages, each stage including a vacuum tube, undesirable coupling between the input circuit of the vacuum tube in one stage and a portion of a succeeding stage whereby undesirable feed-back voltages are impressed upon the grid electrode of the vacuum tube of said stage, a tuning condenser connected across the extremities of a secondary winding of a coupling transformer included in said input circuit whereby said circuit may be tuned over an operating frequency band, the primary winding of said transformer being connected in the output circuit of a preceding vacuum tube and having an effective value of impedance substantially the same as the plate impedance of said preceding vacuum tube as measured at a frequency higher than the minimum frequency of said operating band and lower than the mid-frequency of said band, and a connection from the grid-electrode of said first-mentioned vacuum tube to a tap intermediate the extremities of said secondary winding whereby the feed-back voltages impressed upon said grid are reduced in greater proportion than the signal voltage, and the signal amplification of said amplifier is maintained at an approximately constant value thruout said operating frequency band.

7. In a radio receiving system including an antenna system, a multi-stage high-frequency vacuum tube amplifier, one stage of which is linked with said antenna system by means of a coupling device comprising an antenna inductance connected in the antenna system, and a secondary inductance connected in the input circuit of said stage, whereby signal voltages are impressed upon the grid electrode of the vacuum tube of said stage, undesirable coupling between the input circuit of the vacuum tube in said stage and a portion of a succeeding stage whereby undesirable feed-back voltages are impressed upon the grid electrode of the vacuum tube of said stage, capacity means connected across said secondary inductance for tuning the same to the frequency of said signal voltages within an operating frequency band, said antenna inductance having a value such that the natural period of said antenna system is of a frequency less than the maximum frequency of said band and greater than an intermediate frequency of said band, and a connection from said grid to a point on said secondary inductance intermediate the ends thereof whereby the impedance of said input circuit is limited to a value less than the total impedance of said secondary inductance so that said feed-back voltages are reduced in greater proportion than said signal voltages.

In testimony whereof I affix my signature.

WILLIAM A. MacDONALD.

CERTIFICATE OF CORRECTION.

Patent No. 1,680,424. **Granted August 14, 1928, to**

WILLIAM A. MacDONALD.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, line 98, strike out the word "to" first occurrence; page 2, line 10, for the word "selectively" read "selectivity"; same page, line 82, for the misspelled word "operatiting" read "operating"; line 93, after the word "from" insert the word "both", and line 130, after the word "circuit" second occurrence insert the word "of"; page 3, line 21, for the letter "C" read "G"; and the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 23rd day of October, A. D. 1928.

(Seal)

M. J. Moore,
Acting Commissioner of Patents.

to a tap on said secondary winding intermediate the ends thereof whereby the impedance of said input circuit is limited to a value less than the total impedance of said secondary winding so that said feed-back voltages are reduced in greater proportion than said signal voltages.

6. In a radio signaling system, a multi-stage high-frequency amplifier including transformers coupling adjacent stages, each stage including a vacuum tube, undesirable coupling between the input circuit of the vacuum tube in one stage and a portion of a succeeding stage whereby undesirable feed-back voltages are impressed upon the grid electrode of the vacuum tube of said stage, a tuning condenser connected across the extremities of a secondary winding of a coupling transformer included in said input circuit whereby said circuit may be tuned over an operating frequency band, the primary winding of said transformer being connected in the output circuit of a preceding vacuum tube and having an effective value of impedance substantially the same as the plate impedance of said preceding vacuum tube as measured at a frequency higher than the minimum frequency of said operating band and lower than the mid-frequency of said band, and a connection from the grid-electrode of said first-mentioned vacuum tube to a tap intermediate the extremities of said secondary winding whereby the feed-back voltages impressed upon said grid are reduced in greater proportion than the signal voltage, and the signal amplification of said amplifier is maintained at an approximately constant value thruout said operating frequency band.

7. In a radio receiving system including an antenna system, a multi-stage high-frequency vacuum tube amplifier, one stage of which is linked with said antenna system by means of a coupling device comprising an antenna inductance connected in the antenna system, and a secondary inductance connected in the input circuit of said stage, whereby signal voltages are impressed upon the grid electrode of the vacuum tube of said stage, undesirable coupling between the input circuit of the vacuum tube in said stage and a portion of a succeeding stage whereby undesirable feed-back voltages are impressed upon the grid electrode of the vacuum tube of said stage, capacity means connected across said secondary inductance for tuning the same to the frequency of said signal voltages within an operating frequency band, said antenna inductance having a value such that the natural period of said antenna system is of a frequency less than the maximum frequency of said band and greater than an intermediate frequency of said band, and a connection from said grid to a point on said secondary inductance intermediate the ends thereof whereby the impedance of said input circuit is limited to a value less than the total impedance of said secondary inductance so that said feed-back voltages are reduced in greater proportion than said signal voltages.

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