Oct. 13, 1942. C. R. BURROWS 2,298,926

ELECTRICAL WAVE AMPLIFICATION

Filed May 17, 1941

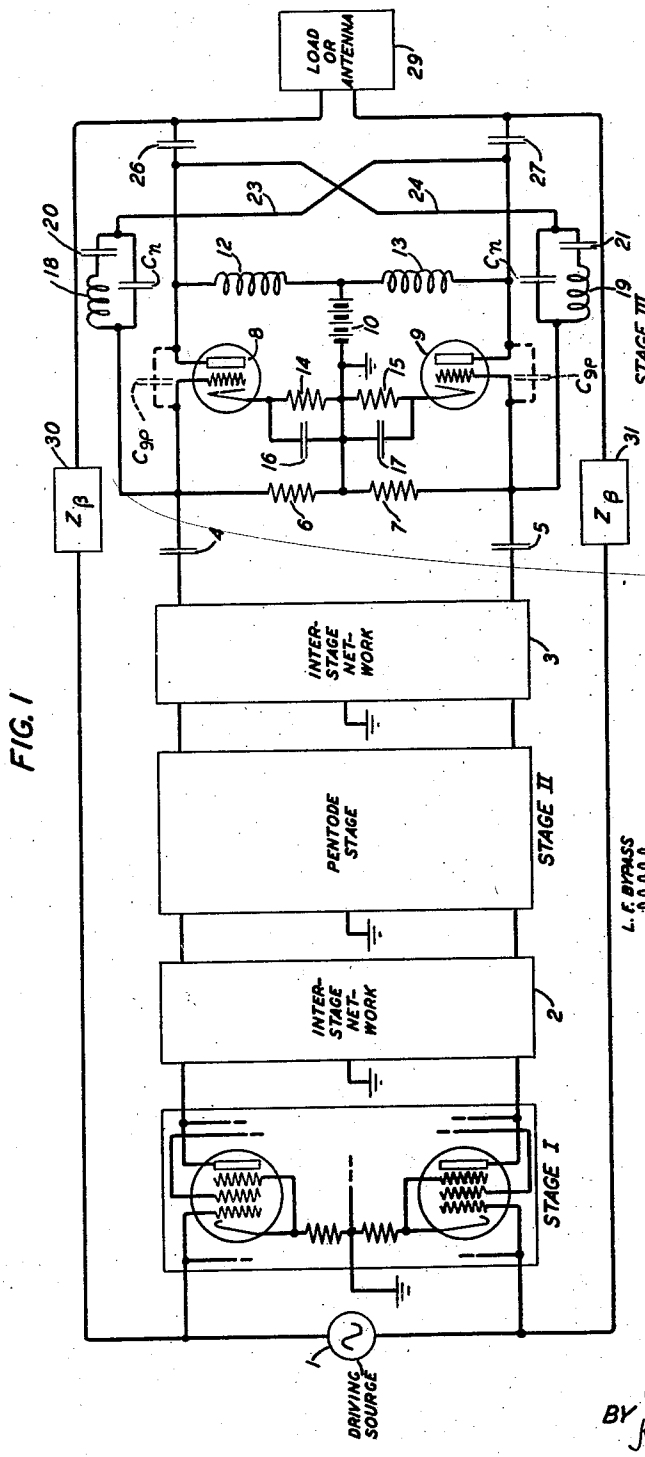

FIG. 1

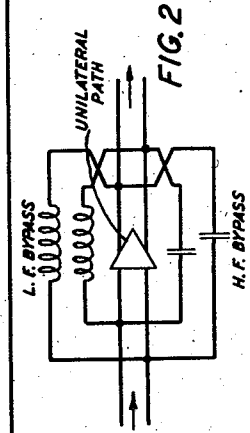

FIG. 2

INVENTOR
C.R. BURROWS
BY W. A. Burgess
ATTORNEY

Patented Oct. 13, 1942 2,298,926

UNITED STATES PATENT OFFICE

2,298,926

ELECTRICAL WAVE AMPLIFICATION

Charles R. Burrows, Interlaken, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application May 17, 1941, Serial No. 393,908

5 Claims. (Cl. 179—171)

This invention relates to the amplification of high frequency waves.

Power tubes as used in radio frequency transmitters are of the triode type, and possess sizable grid-to-plate capacity. It is usual to apply to them some form of neutralizing circuit for reducing the effect of the grid-to-plate capacity. A known form of capacity-neutralizing circuit is the so-called bridge type, which in the case of a push-pull stage takes the form of a pair of crossed condensers, one from each grid to the opposite plate.

The gain obtainable from such a stage is relatively low but it is common practice to precede such a stage by one or several low power high gain stages. In order to improve the circuit operation from the standpoint of signal-to-noise ratio, linearity or stability, a negative feedback circuit may be connected around the amplifier as a whole.

I have found that the phase-gain characteristic of such a system using over-all negative feedback can be improved at frequencies remote from the operating frequency by making the crossed neutralizing capacities extra large and neutralizing their excess capacity at the operating frequency by anti-resonating it in each case with an inductance. Such a circuit becomes a unilateral transducer in the operating frequency band but allows forward transmission in aiding phase at frequencies remote from the band so that the amplifier has increased singing margin and permits the use of an increased amount of negative feedback.

The nature and objects of the invention will appear more fully from the detailed description to follow, taken in conjunction with the drawing.

In the drawing, Fig. 1 is a schematic circuit diagram, partly in block form, of a radio transmitter embodying the invention; and

Fig. 2 is an explanatory diagram to be referred to in describing certain transmission characteristics of the circuit of Fig. 1.

Referring to the drawing, Fig. 1, the driving source 1 may in practice comprise a source of speech modulated or signal modulated radio frequency waves, which are to be amplified and then radiated or otherwise utilized. The amplifier may be of quite general configuration so far as the present invention is concerned but for illustrative purposes is shown as a multistage amplifier including a triode power stage as the final stage preceded by stages which are primarily voltage amplifying stages, illustrated as employing pentode tubes. There is nothing in this configuration which is to be taken as limiting since there may be more than one power stage and in practice the amplifier might comprise more than the three stages shown, for example, four, five or six, etc., stages. Stage I and II may be of conventional design as may also be the interstage coupling networks 2 and 3 or these latter may be designed to have suitable characteristic from the standpoint of the over-all feedback. The driving source 1 may be the modulator itself or may include an amplifier (buffer amplifier) following the modulator. The pentode stages and the interstage circuits are shown balanced with respect to ground.

The output side of interstage network 3 is shown coupled through series capacities 4, 5 and shunt resistors 6, 7 to the grids of respective triodes 8, 9. The plates of this stage are fed from source 10 through plate radio frequency chokes 12, 13 and the usual grid bias resistors 14, 15 are included in th cathode leads, with the usual by-pass condensers 16, 17.

These triodes are indicated as having an internal grid-plate capacity C_{gp}. Crossed condensers C_n, C_n are connected one from each grid to the plate of the opposite triode to provide bridge neutralization of the capacities C_{gp}. These neutralizing condensers, however, have excess capacity over that required for exact neutralization, and the inductances 18 and 19 are connected in parallel with respective condensers C_n and proportioned to antiresonate with the excess capacity over that required for exact neutralization, at the operating frequency. Condensers 20, 21 are stopping condensers.

The output terminals of tubes 8, 9 lead through series capacities 26, 27 to the load 29 which may be a radiating antenna or other suitable utilization circuit such as a transmission line.

Over-all negative feedback is provided by conductors leading from each triode plate to the input side of the first pentode stage through respective feedback networks 30, 31 labelled $Z\beta$, which may be variable and may comprise simply resistance or may be networks of suitable characteristic. Other types of negative feedback connection could be used instead of the connection as shown. The feedback reduces the gain in the operating range and the early stages should provide excess gain to allow for the gain reduction due to feedback. As is known, the feedback improves linearity, gives greater signal-to-noise ratio for certain types of noise, and increases gain stability, the improvement being greater the greater the gain reduction.

A bridge-neutralized push-pull amplifier is theoretically neutralized at all frequencies since the bridge arms are equal capacities. Due to that part of the capacity except the excess capacity included in condensers C_n, the push-pull tubes 8, 9 may be considered as neutralized at all frequencies. While the excess capacity in condensers C_n would of itself over-neutralize the stage at the operating frequency, this tendency is cancelled by the parallel inductance 18 or 19, so that at the operating frequency the stage is exactly neutralized. At frequencies higher than the operating range the excess capacity in the upper condenser C_n affords a low impedance path from the grid of tube 8 through lead 23 to the plate of tube 9, and similarly there is a low impedance path from the grid of tube 9 through the excess capacity and lead 24 to the plate of tube 8. At frequencies lower than the operating range, similar paths exist through the inductance 18 and lead 23 and through inductance 19 and lead 24. It will be noted that currents flowing through these crossed paths from the input to output sides of the tubes 8, 9 are reversed in phase so that they add in phase to the currents transmitted through the triodes by means of their transconductance, which currents undergo phase reversal from grid to plate.

This action is represented in the explanatory or functional circuit of Fig. 2 in which the push-pull stage 8, 9 is represented as providing three possible paths from input to output: a unilateral path at all frequencies, this being the bridge-neutralized triodes; a high frequency by-pass with a cross-over to indicate phase reversal of the currents transmitted through this path; and a low frequency by-pass, also with a cross-over.

It is found in practice that these paths through the excess capacity in the case of the very high frequencies and through the neutralizing coils in the case of the very low frequencies, contribute a helping phase in the over-all feedback loop, so that their presence makes possible the use of a larger amount of negative feedback in the operating range without violating gain-phase requirements for singing margin in the cut-off regions. This may be seen from considering that the capacities C_{gp}, if not neutralized, would contribute to the singing phase since they would permit through-transmission without undergoing the phase reversal occurring in the amplified waves between grid and plate. Neutralization of these capacities gives an improvement in singing margin and the invention achieves a still further improvement by permitting forward transmission in opposite phase to that which would take place through the C_{gp} capacities in an unneutralized amplifier. The amount of the excess capacity that is used over that required for exact neutralization can be varied within wide limits depending upon the type of frequency characteristic desired. By way of example, a value of such excess capacity substantially equal to the capacity C_{gp} has been found suitable in a particular case.

It is known that the bridge-neutralizing capacities increase the total capacity existing across the circuit from grid to grid and also from plate to plate. One effect of this is that the pentodes in stage II work into an impedance which has a greater capacity component than would be the case if the neutralizing capacities were absent. The gain of the pentode stage has a tendency to fall off with increasing frequency above the band because of the shunt capacity of the load and this tendency is increased by the presence of the neutralizing capacities. This tendency is counteracted, however, by the gain characteristic of the triode stage by virtue of the excess capacities provided by the invention since these tend to hold up the gain of the triode stage at high frequencies by contributing to the useful transmission through the triode stage. It is found that the gain of the pentode stage and triode stage in tandem varies in some inverse ratio to the first power of the frequency instead of inversely as the square of the frequency.

The invention is not to be construed as limited to the details of the illustrative embodiment that has been disclosed but the scope is defined in the claims, which follow.

What is claimed is:

1. A push-pull amplifier stage comprising space discharge devices whose grid-plate capacity is appreciable at the operating frequency, crossed condensers providing bridge-neutralization of the grid-plate capacities, said crossed condensers comprising excess capacity to produce over-neutralization of said grid-plate capacities, inductances shunting said crossed condensers for neutralizing their excess capacity, and a negative feedback loop serially including said stage.

2. A negative feedback amplifier comprising in one stage thereof triodes connected push-pull, crossed condensers for neutralizing the grid-plate capacities of said triodes, said condensers possessing capacity in excess of that required for exact neutralization of said grid-plate capacities, and inductances paralleling said condensers and having such values as to neutralize such excess capacity at the operating frequency.

3. A high frequency high power amplifier system comprising at least one push-pull pentode stage feeding into a push-pull triode stage, said pentode stage providing voltage amplification and said triode stage providing power amplification, crossed condensers in said triode stage connected one from each grid to the plate of the opposite triode for neutralizing the grid-plate capacities of said triodes, said condensers possessing capacity in excess of that required for exact neutralization of said grid-plate capacities, an inductance in shunt of each of said condensers for neutralizing said excess capacity at the operating frequency, said condensers by virtue of said excess capacity providing forward transmission between input and output sides of said triode stage of currents of higher frequency than the operating frequency in phase with the transmission through the triodes such as to compensate in over-all gain the drooping gain characteristic of the pentode stage working into said neutralized triode stage and a negative feedback path connected around said stages.

4. In an amplifier, a pair of triodes connected push-pull, crossed condensers connected from each grid to the plate of the opposite tube for neutralizing the grid-plate capacities of said triodes, a negative feedback connection around said stage, means for improving the singing margin of said amplifier comprising capacitance between each grid and the plate of the opposite triode, in addition to the capacity required for neutralizing said grid-plate capacity of said triodes, such additional capacitance serving to transmit from the input side to the output side of said triodes waves in aiding phase to those transmitted by the triodes at frequencies approaching the high cut-off region of the ampli-

fier, and means to neutralize such additional capacitance in the operating frequency range.

5. An amplifier according to claim 4 in which said last means comprises a pair of inductances respectively shunting said crossed condensers and antiresonating with the additional capacitance at the operating frequency, said inductances serving to improve the singing margin of said amplifier at low frequencies by transmitting from the input to output sides of said triodes currents in aiding phase to those transmitted by the triodes at frequencies approaching the low cut-off region of the amplifier.

CHARLES R. BURROWS.