A New Electron Tube

Furnishing at Radio Frequencies an Amplification of 40 Per Stage

By SYLVAN HARRIS

EVER since the great development of radio began, that is, within the last fifteen or twenty years, there has been a crying need for an electron tube which would enable us to amplify small voltages at radio frequencies, without having to battle that ever-present difficulty known as regeneration. It is well known that regeneration in radio-frequency amplifiers is due to a feed-back of energy, from the plate circuits of these amplifiers to the grid circuits, through the inter-element capacities within the tubes.

The small capacities existing within the tubes, that is, between the grid and plate, between the grid and filament, and between the plate and filament, although very small in actual magnitude (being about 10 micro-microfarads or thereabouts in the 201A type of tube) have a considerable effect on the operation of radio-frequency amplifiers, especially at frequencies above, say, 750 kilocycles per second (400 meters). To be exact, the feed-back of energy depends upon the reactance of these small condensers in the tubes; and, as the frequency becomes higher and higher (that is, the wavelength becomes shorter and shorter), this reactance becomes less and less.

On account of this, the small capacities within the tubes can pass quite a large feed-back current at the higher frequencies, with the result that the regenerative effects are very pronounced at these frequencies, and sometimes difficult to control.

CONTROL OF REGENERATION

The regeneration in an electron-tube circuit depends upon five important factors, viz.: the capacities between the electrodes in the tube (principally between the grid and the plate); the inductance in the plate circuit of the tube; the internal plate-resistance of the tube; the frequency of the signal voltages to be amplified; and the resistance of the tuned circuits.

In order to keep the regeneration below the critical point at which self-oscillation occurs, it is necessary to introduce into into

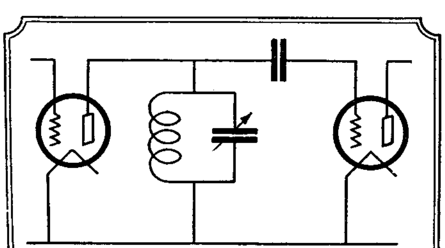


FIG. 1

In a simple circuit like the above, regenerative effects are the drawback of high-amplification tubes.

the circuits means of controlling these factors:

(a) First, we might eliminate the effect of the grid-plate capacity of the tube by balancing it out in a bridge network, or by some other neutralizing scheme.

(b) Although we may not be able to eliminate successfully the inductance in the plate circuits of the tubes, we might eliminate its effect, which leads us to the so-called "zero-reactance plate circuit." Nothing concerning this form of circuit has as yet appeared in print, but the writer has in preparation an article on this subject which he hopes to publish soon.

(c) The "B" voltages impressed on the plates of the tubes may be kept small; when this is done the tubes are operated under such conditions that their plate resistances are high. This means a considerable reduction of the efficiency of the circuit.

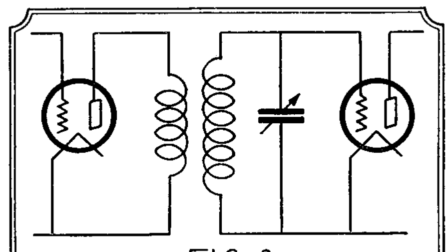


FIG. 2

Another familiar circuit, in which unwanted regeneration is a governing factor.

(d) The tuned circuits may be made very inefficient, having in them plenty of resistance or other losses. This applies also to the interstage coupling transformers, which are generally very inefficient because of the very small mutual inductance between the two windings.

Now, it is clear that, by doing any or all of these things except perhaps the first, we are impairing the efficiency of the amplifier. As concerns neutralizing the tube capacities, we cannot discuss this very much here; it is well known, however, that these neutralizing schemes have limitations which militate against designing radio receivers to give amplifications per stage of more than perhaps 15, or in some cases perhaps 20. Many of the bridge circuits do not balance perfectly over the whole range of broadcast frequencies; and those for which it is claimed they do, have other limitations.

METHODS OF COUPLING

Suppose we consider a simple circuit like that shown in Fig. 1. We can design the tuned circuits between the tubes to have very little resistance; and so, when tuned to the frequency of the impressed signal voltage, they would give us a coupling impedance which would be extremely great. Under such conditions there would be little or no loss of amplification in the couplings between the tubes and, if it were not for the regenerative effects which we would encounter, we could build the tubes to give any amount of voltage amplification we desire, even perhaps a hundred or more.

But, as you know, when we try a circuit like this, we have to use a potentiometer or some other means to control the tendency to oscillate; for we have in the plate circuits a large inductive reactance and we also have the capacities within the tubes.

Or, let us consider the circuit in Fig. 2, with which most of us are acquainted. If we could simply go ahead and increase the mutual inductance between the primary and secondary windings to any amount we please, or make it as great as we can, we could get a lot of amplification out of this system, perhaps almost as much as we could get out of that in Fig. 1. But here again we run into the snag of regeneration and self-oscillation; so we have to stop adding turns to the primary long before we have a resonance transformer whose efficiency is worth talking about.

In recognition of these failings of radio-frequency amplifiers, hundreds of methods of controlling regeneration and oscillation have been devised, but they are all more or less alike in the results they produce. Manufacturers of tubes have tried for a long time to build tubes with small internal capacities. But they found that, when they tried to reduce the intra-electrode capacities, they had to reduce the amplification factor at the same time, or raise the internal plate-resistance; so that it became a matter of "six of one and a half a dozen of the other."

THE "SHIELDED GRID"

Lately, Dr. A. W. Hull, of the General Electric Company, has devised an electron tube in which the capacity between the grid and plate is so small that it cannot be detected and measured by the most sensitive means. The means by which this was done were originally devised by Dr. Schottky, a German scientist. Instead of trying to remove this capacity actually from the tube (which, of course, would be impossible, since electrodes are required in the tube to make it operate) the *effect* of this capacity was eliminated by using what is known as the *"shielded grid"* principle.

The idea of this is to prevent, as far as possible, any of the electrostatic lines of force (which we always have between the plates of a charged condenser) from passing from the plate or any of its connecting wires to the grid or any of its connecting wires. This is done by placing between the grid and plate an electrostatic shield, which is given a certain bias and cuts off these electrostatic lines. At the same time this shield must be so arranged that it does not appreciably block the electrons as they flow from the filament to the plate; for it is upon the flow of these electrons that the operation of the tube depends.

There are two parts to the shielding. First, the grid itself must be shielded from

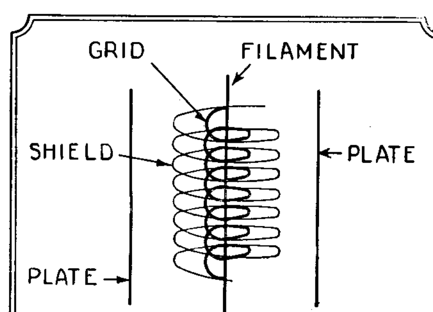


FIG. 3

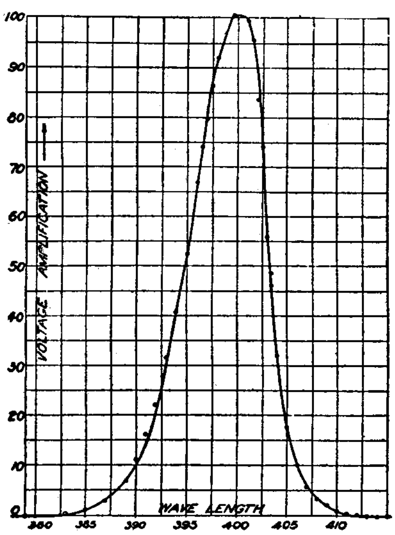
The principle of Dr. Hull's new tube, showing the position of the shield relative to the other elements.

the plate by an interposed shield. This shield may consist of a wire wound around the grid, the latter being of the coil type, and which is so placed that at every point the two coils of wire are opposite. This idea is illustrated in Fig. 3, which does not show the actual construction, but only the idea. Measurements made by Dr. Hull, however, showed that this type of shielding is not sufficient; as the wires must be so close together in order to obtain sufficient shielding that they intercept a considerable proportion of the electrons flowing from the filament to the plate.

On account of this, the shield was made of thin, wide slats, placed edge-on toward the filament. In this way the shielding could be made very effective, without blocking any appreciable part of the electron flow.

LATEST IMPROVEMENTS

Next the supporting wires and the lead-in wires of the grid had to be shielded effectually from the plate and its supporting and lead-in wires. To accomplish this the grid was supported from the top of the tube. But, in spite of this, there are still some electrostatic lines of force which pass through space from the grid to the plate, and are likely to result in trouble. In order to intercept these the tube was covered by a grounded metal cylinder, fitting the tube closely; and finally a metal disc was attached to the top of the "screen-grid" and connected to the grounded cylinder. The accompanying Fig. 5 (taken from the *Physical Review,* in which Dr. Hull reports



Selectivity curve of a 4-stage amplifier with input untuned, at 1,000 kc.

his work) shows the construction of the tube.

The static characteristics of these tubes are different from those of the ordinary tubes with which we are acquainted; but we will not go into these here, excepting to say that they differ mainly in the plate resistance. The effective capacity between the plate and the grid of one of these tubes was found by Dr. Hull to be 0.0278 micro-microfarad, contrasted with about 10 to 15 for the ordinary 201A type of tube. This amounts to a reduction of the grid plate capacity to about one five-hundredth of what we have in the 201A type of tube.

In testing out these tubes, the circuit shown in Fig. 4 was used. The screen-grids were maintained at 60 volts and the plates of the tubes at 110 volts. The output voltage of this radio-frequency amplifier was measured by a calibrated detector tube.

The small voltage required at the input of the amplifier was obtained by connecting the input across a short piece of wire which was surrounded by a concentric return conductor. The input voltage was then equal to the reactance of this short copper rod multiplied by the current through it, which was measured by means of a thermocouple.

In making these measurements, Dr. Hull found that no advantage was gained by using any kind of a step-up transformer arrangement for coupling the tubes together. This is on account of the high plate-resistance of the tubes, which enables them to work efficiently into very high impedances, such as the type shown in Fig. 1; which was finally used, as the circuit of Fig. 4 shows. This diagram shows the complete connections of Dr. Hull's amplifier and measuring equipment.

ENORMOUS AMPLIFICATION

Some measurements made at 50 kilocycles, or 6,000 meters, showed that it was possible to obtain amplification of 200 per tube. When tested at medium frequencies, around

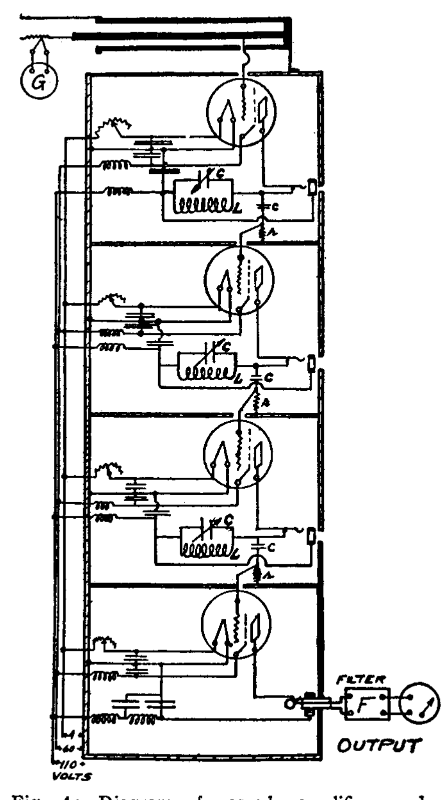


Fig. 4: Diagram of cascade amplifier used for tests at 1,000 and 10,000 kc. Input at upper left.

1,000 kilocycles, or 300 meters, they gave voltage amplifications between 40 and 45 when operated singly. When operated in cascade, two tubes were found to give an amplification of 1,700, and three tubes, of 75,000. In other words, at these frequencies an amplification of about 40 to 45 per tube could be counted on. It is interesting to contrast this with the gain in our ordinary radio-frequency amplifiers, where we obtain not more than fifteenfold amplification.

As for the actual effects of such tubes on an audio amplifier, if we were to use them in a regular receiver, we must not forget that the detector operates according to a *square law.* That is, if we have a voltage e impressed on the detector, the output voltage of the latter is e^x proportional to e^2. Let us suppose that, in a *very* sensitive receiver of the ordinary kind, we can obtain a gain of 10 per stage. In Dr. Hull's receiver, a gain of 40 per stage can be obtained at 1,000 kilocycles. This is four times as great *per stage.* Suppose we consider three radio-frequency amplifier stages. This means an amplification 64 times that of our ordinary good receiver. And finally squaring this in the detector, we have an output from the detector which is 64x64, or about 4,000, times as great as the output of the detector in the ordinary good receiver. And this means, that, barring static and other disturbances, it would be possible to detect signals 1/4000th as strong!

Using a complete set of five tubes, the last a detector, a total amplification of 2,000,000 was obtained.

In all these tests no trouble was experienced from feed-back, except at first. Where separate batteries were used for several of the stages, this trouble disappeared, as it

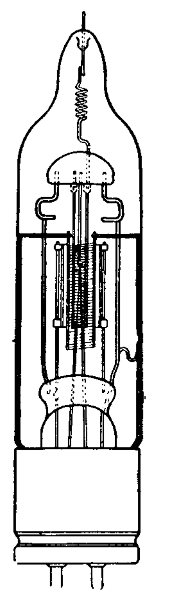


Fig. 5: Sketch of Dr. Hull's new tube, showing method of shielding the control grid from the plate.

Illustrations on this page courtesy of The Physical Review.

might have done if better filtering or by-passing of the R.F. had been obtained in the various stages.

At high frequencies, it is not possible to obtain such great amplification, since the resistance and dielectric losses are so large. This makes it difficult to obtain high impedance by resonance. At 30 meters (10,000 kilocycles), however, several tests were carried out, and a total amplification of 250 was obtained with five tubes. In another test, using special low-loss coils made of copper tubing, and other losses reduced considerably, the voltage amplification per stage was raised from three to seven; and it was found possible to obtain an overall amplification of between 10,000 and 15,000, using five tubes.

Tubes of this type, however, according to Dr. Hull's paper in the *Physical Review,* are not being manufactured, nor is their immediate production contemplated.