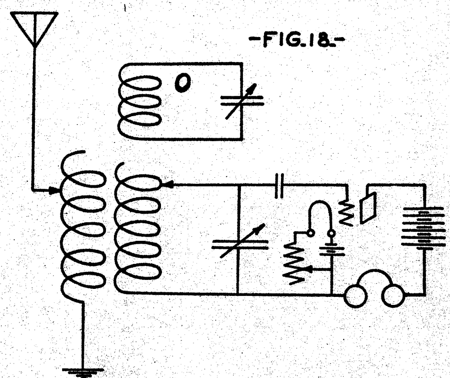
Applications of the Audion

By Paul F. Godley.

(Concluded)

In the construction or selection of receiving transformers or variometers for use on wave lengths, say, under 700 or 800 meters, I wish again to call attention to the importance of the free use of the wave meter in order that the natural wave length of the coils of which the instrument is comprised may be ascertained. (Fig. 6) For example, if



-FIG. 18-

it should be found that the secondary coil of a receiving transformer had a natural wavelength of 300 meters (and this is by no means unusual) the coil would not be at all suitable for the efficient reception of waves nearer than 20% above or below 300 meters, e. i. waves between 240 and 360 meters. Provided such a transformer is to be used for reception through this range, it should either be altered to suit conditions, or substituted, for reasons which have been mentioned.

In this connection an interesting and enlightening experiment may be performed by quite closely coupling a closed oscillatory circuit to the secondary of a receiving circuit as in Fig. 18. After the primary and secondary circuits have been tuned to an incoming signal, if circuit "o" is also adjusted it will be found that the signal strength decreases to a decided extent as the circuit approaches and passes through resonance.

The relation of this experiment to the foregoing discussion is apparent. If this experiment is tried in conjunction with a regenerative or oscillating audion circuit, the effects produced will be particularly marked.

A small no-end-loss receiving transformer designed by the writer is shown in Figure 19. This instrument is of the size usually purchased by the amateur. However, when constructed in the conventional manner both the primary and secondary coils have natural periods within the range for which the instrument was originally designed. Measurement showed the primary to have a natural wavelength of 235 meters, and the instrument shown in Figure 19, but of much greater range. Before division into sections the primary and secondary coils of this instrument had natural wavelengths of 390 and 860 meters respectively. The transformer was unsuitable for use on wavelengths below 1,000 meters. Though much more difficult to accomplish, a proper division of the coils, brought about the entire removal of undesirable false resonance points, and the larger instrument became as efficient through the range of shorter waves as the smaller one. Figure 21 is another view of an instrument of

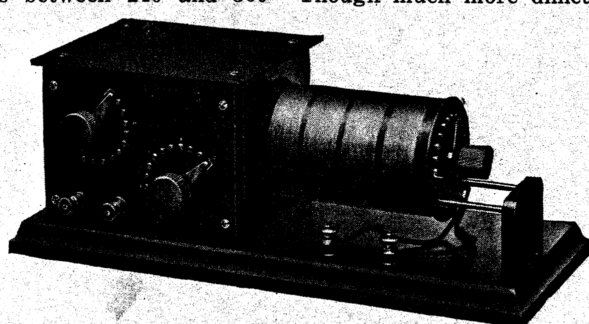


Fig. 19

this pattern, showing the type of end switch employed, and the divisions of the primary winding.

Figures 22 and 23 show a receiving set designed for the extreme ranges, e. i; 180 to 20,000 meters. The circuits employed are combinations of those given above. Below 4,000 meters variometers alone are used as inductances, coupling between the circuits being provided externally. Above 4,000 meters the circuits are "'loaded." Loading inductances are of the "thin" multi-layer type, and the coupling between the loading coils is variable. Attention is called to the placement and directness of all leads, inasmuch as this is of material aid in keeping capacity effects at a minimum, and in the reduction of counter-inductive action.

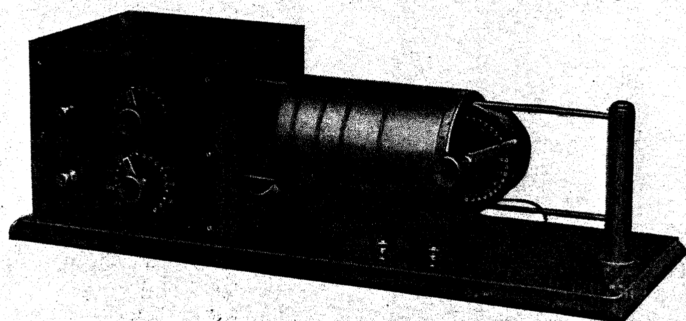


Fig. 20

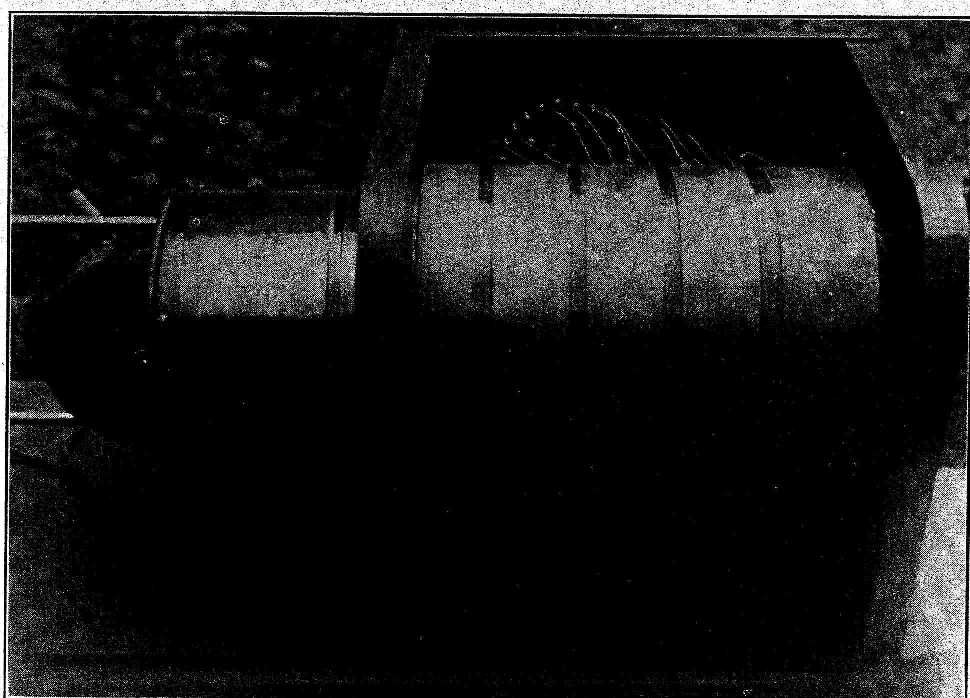


Fig. 21

Figure 24 shows two audion circuits similar to those described coupled together for cascade operation. Although there are various ways of operating this combination, it will usually be found to operate with less difficulty when the first audion is used to amplify signals at radio frequencies without generating local oscillations, the second audion serving the purpose of rectifier, generator and amplifier. This may be accomplished by the omission of the stopping, or grid, condenser in the circuit of the first audion. On spark signals the results obtained by the writer with this circuit have not been remarkable. On continuous waves, however, amplifications as high as 500 to 700 times are easily possible.

In Figure 25 a circuit for a combined radio telephone and telegraph transmitter and receiver complete is shown. It will be noticed that the antenna and wing circuits

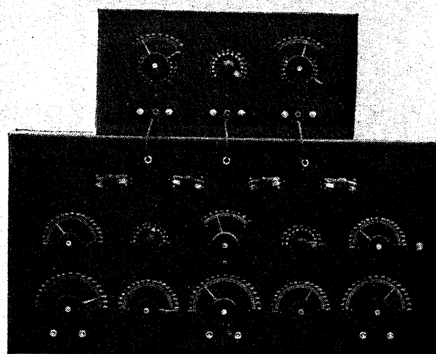


Fig. 22

are coupled directly to the grid circuit inductance. This makes for stability of operation and, greater radiation. The secondary of an ordinary telephone induction coil is placed in series with a leak resistance of somewhere in the neighborhood of 100,000 ohms (graphite rod) and the combination is of course placed in series with a trans-shunted direct from the grid to the filament. The leak resistance should be shunted by a capacity of approximately .0005 mf in order

place. Any increase in voltage will give a corresponding increase in radiation. Using one audion connected in this manner, the writer has found it possible to transmit with ease, either radio-telephonic or radio-telegraphic signals at will over a distance of 1,000 feet, using at the receiving station, which was incidentally in an automobile, a receiver of the regenerative type. Using this same circuit, several audions may be placed in multiple, providing their characteristics are not radically different. By placement in multiple, is meant the connection of all grids, wings and filaments together respectively, only one grid condenser, one high-tension battery and one lighting battery being used. In a circuit such as this where larger amounts of energy are dissipated, the small flash-light batteries

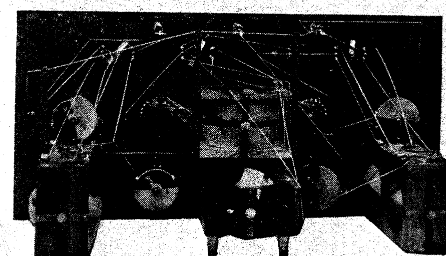
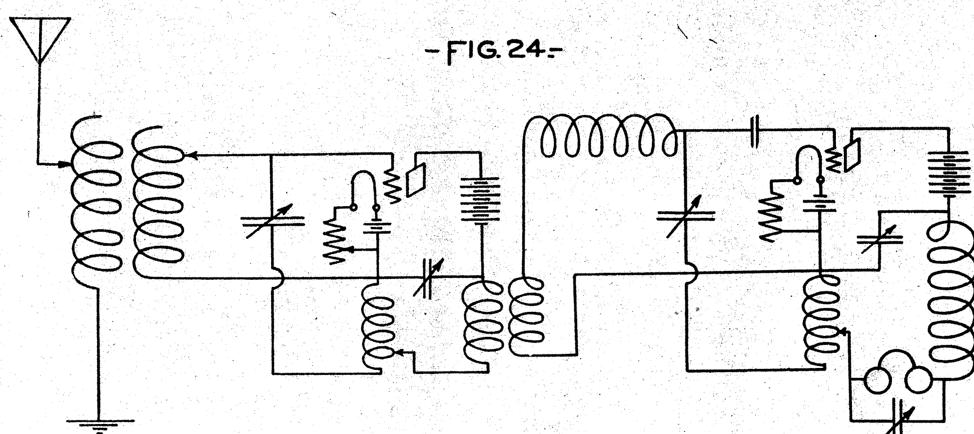


Fig. 23

usually used in connection with the audion, will give only short service. This may be gotten around

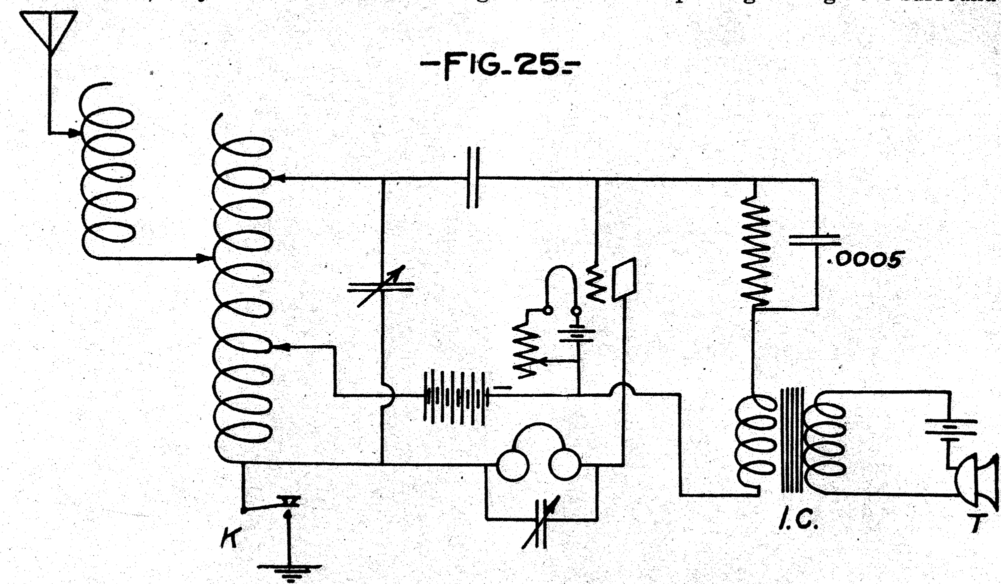
-FIG. 24-



that the voice currents may pass freely. The primary of the telephone transformer mitter and battery. This arrangement gives the voice excellent control of the system. The key in the ground circuit permits the formation of telegraphic characters. Once oscillating, it is possible to increase the wing circuit voltage to quite an extent without causing ionization to take

economically by providing small storage cells which may be constructed with test tubes an inch in diameter and five or six inches deep. Strips of thin lead are cut for plates and scratched deeply with a sharp knife so that as much surface as possible may be presented to the electrolyte. Two plates are to be placed in each test tube and separated by a thin strip of porous wood. Seventy-five or one hundred of these cells may be constructed in a fairly short time and placed in a rack made by boring holes in a board. After they have been "worked in" by charging and discharging a few times, they will take sufficient charge

-FIG. 25-



to supply several audions for a good many hours. A cell of this sort, if carefully constructed, should have about one-quarter ampere-hour capacity.

In conclusion, it might be said that every day new audion circuits are "discovered." They are, however, with but rare exceptions the ones with which we are familiar turned wrong side out, and unfortunately they have usually suffered in the turning. On the other hand, there are a great number of very excellent applications of the audion circuits mention of which time will not allow. It is to be hoped however, that what little of interest I have been able to present, may at least suggest to you something of greater interest.

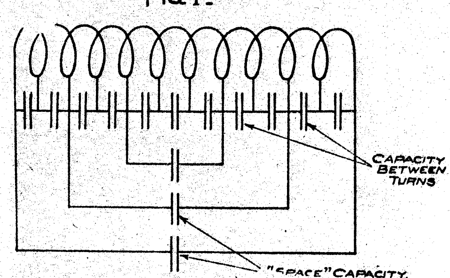
DISCUSSION

Prof. L. A. Hazeltine.

Mr. Godley has properly emphasized the importance of minimizing the distributed capacity in radio receiving coils, especially for short waves. It is even more important, however, to minimize the resistance—or better, to make the quotient (L/r) of self-inductance by resistance as high as possible. It is my purpose to show that these results can be obtained better by the use of multilayer coils than single-layer coils.

In Mr. Godley's Fig. 5, he represents the distributed capacity of a single-layer coil as existing between adjacent turns only. In reality, the greater part of the capacity exists between one end of the coil as a whole and the other end, as represented in Fig. 1 herewith. In other words, the capacity is due partly to dielectric flux passing from turn to turn, but mainly to dielectric flux passing through the surrounding space, inside and outside the coil, as represented in Fig. 2. This is proved by re-

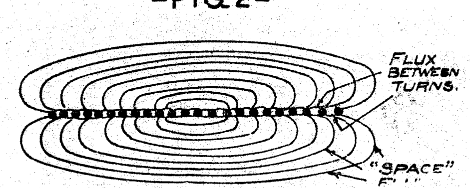
-FIG. 1-



sults of Drude*, which show that substituting thin silk insulation for thick cotton insulation, and so decreasing the ratio

$$\frac{\text{diameter outside insulation}}{\text{diameter of bare wire}}$$

-FIG. 2-

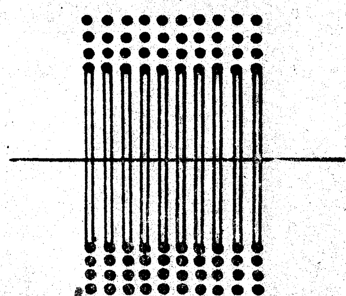


*Annalen der Physik, 1902, IX, p. 322. See also paper by Howe, Proc. Phys. Soc. (London), 1912, p. 251.

from 2.4 to 1.09, increases the capacity of a closely wound coil (having a length equal to its diameter) by less than 20%. The capacity between turns, however, would then be multiplied by about 3.6; so it must be a small part (less than 10%) of the total capacity. Further, Drude's results show that substituting an ebonite core for an air core increases the total capacity by nearly 40%, while it could have very little effect on the capacity between turns.

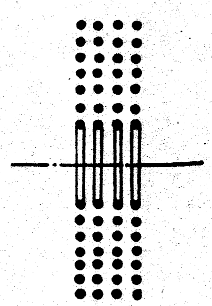
Bearing in mind the above results, it can be seen that a coil made up of pancake sections, having say 4 turns each, as represented in Fig. 3, will have very little in-

-FIG.3-



crease in capacity over a single-layer coil of the same dimensions; for the space capacity remains the same and the capacity between sections is still a small part of the total. The self-inductance however, has been increased nearly 16 times, and the resistance only 4 times; so the coil has been

-FIG.4-

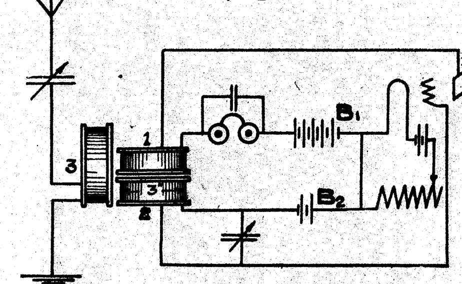


greatly improved by having a higher value of L/r. If we wish, we may now slightly reduce the dimensions of this coil until its capacity returns to that of the single-layer coil, when we will find its value of L/r is still several times that of the single-layer coil.

It is difficult to wind a coil as in Fig. 3, on account of the connections between sections, unless an excessive space is left between these. Hence it is convenient to interchange the length and depth of the winding cross-section, giving a short, deep multilayer coil, as in Fig. 3, having essentially the same constants as the coil of Fig. 4, with corresponding dimensions. The design of such coils has been taken up by the writer in this discussion of Mr. Eastham's recent paper before the Radio Club, and so will not be considered here in detail. It might be well to mention, however, that for most purposes it is not desirable to use such a short deep cross-section as in Fig. 4, as this unduly sacrifices L/r for the sake of a low capacity. In the coils designed and constructed by the writer, the capacity between layers (which corresponds to the "capacity between turns" of a single-layer coil) is considerably higher than the space capacity; but on account of the small dimensions, the total capacity is of the same order of magnitude as found in receiving sets using single-layer coils.

Taps for tuning should not ordinarily be employed in multilayer coils; for the turns are all so near one another that the coil would act as a step-up transformer, causing the effective capacity to increase nearly as fast as the self-inductance was decreased.

-FIG.5-



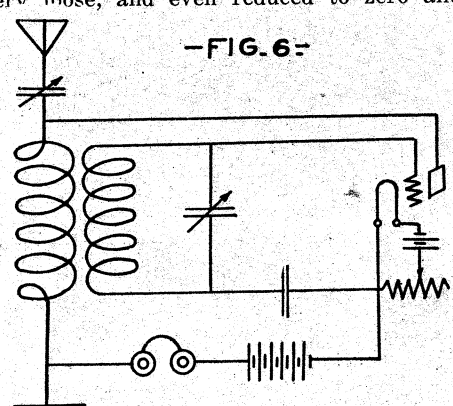
In fact, in the ideal case when all turns are linked with the same magnetic flux, the natural wave length would be the same, no matter what taps were in use. Tuning should therefore be done mainly by variations in capacity.

In Fig. 5 is shown the connections and general arrangement of the apparatus used by the writer for receiving undamped-wave signals up to 15,000 m. wave length. Coils 2 and 3 are 3 inches in diameter and are wound with about 1,200 turns of 10 × No. 38 Litzendraht with 6.5-mil paper between layers. Coil No. 1 has about 200 turns, but 500 would probably be better. The antenna condenser has about 2 millimicrofarads (0.002 microfarad) maximum capacity. The maximum grid capacity is about half this. Instead of the usual stopping condenser, a biasing battery B2 of 5 to 10 volts is often used.

The mathematical theory of the circuit of Fig. 5 is relatively simple, but would be out of place here. Suffice it to say that with sufficient coupling between coils 1 and 2, the audion is capable of producing oscillations at the two natural frequencies of the coupled circuits 2 and 3. Under the following conditions these two oscillations will occur with equal ease; (a) very small or zero coupling between coils 1 and 3, as represented in Fig. 5; (b) circuits 2 and 3 tuned to the same frequency; and (c) coil 1 having a natural frequency much higher than that of circuits 2 and 3. If under these conditions a stopping condenser is used instead of the biasing battery B2, oscillations of the two natural frequencies may exist simultaneously, giving their "beat" note in the telephone receivers. With a biasing battery, as shown, this note will be heard only momentarily as a "tweet" when adjustments are being made; for only a single oscillation is then stable. If now the circuits are tuned up so that the audion oscillates at one natural frequency while the incoming signal has the other natural frequency, enormous amplification is possible. The note heard in the telephone receivers under this condition depends on the coupling between coils 2 and 3. In fact, the ratio of the audio frequency to the radio frequency is approximately equal to the coefficient of coupling, and should lie between about 2% and 5%, a result conveniently attained with the arrangement of Fig. 5. The greatest amplification of signals occurs when the audion is barely oscillating, which is attained by reducing the coupling between coils 1 and 2. The compactness and ease of manipulation of this arrangement are obvious.

For damped wave reception the writer uses the connections of Fig. 6, which gives only one frequency of oscillation at a time. Coupling between the coils can be made very loose, and even reduced to zero and

-FIG. 6-



reversed, the greatest amplification occurring when oscillation just ceases. For wave lengths from 200 m. to 800 m., coils 1.5 in. to 2 in. in diameter have been used. Attention is called to the fact that the stopping condenser of Fig. 6 is shown adjacent to the filament instead of adjacent to the grid as is common: this is to keep it near ground potential and so eliminate its capacity. For the same reason the wing is connected directly to the ungrounded side of the antenna coil, the telephone receivers and battery being on the ground side. With slight additions, this circuit has been used for transmitting and receiving undamped wave signals both for telegraphy and telephony.

Mr. Godley: In order to determine the relative merits between single layer coils and the multi-layer coils of which Professor Hazeltine speaks, I am of the opinion that information concerning the **actual** relationship existing between the inductance and capacity of such coils is essential. It is unfortunate that no such information is available. It is extremely doubtful whether or not the increase in value of L / C in this type of coil, if any, warrants constructional difficulties encountered, especially on the part of the experimenter, since, as I remember it, the specifications as given by Professor Hazeltine, call for coils with no core and no supports, because, as he pointed out the presence of a dielectric in and surrounding the coils very greatly increases the capacity.

Taps on a multi-layer coil are usually undesirable as Professor Hazeltine has stated. This would be especially true in connection with a multi-layer coil designed for covering the shorter ranges of waves. A variation of inductance is essential for good short wave reception (unless possibly a separate coil be used for each small range of wavelengths) and we are led to assume that the statement concerning the unsuitability of multi-layer coils for short wave work under any conditions, still stands.

When using a biasing battery to replace the grid or stopping condenser as in Fig. 5 of this discussion, a decrease in sensitiveness is to be expected. This arrangement, however, is sometimes advantageous during heavy static.

The circuit shown in Figure 6, is by no means a selective circuit due to the direct coupling of the wing and antenna circuits. The placement of the stopping condenser in the filament, or low potential lead (low potential with respect to the earth) also renders the circuit more susceptible to shock excitation. To be sure, the capacity of the stopping condenser has been greatly decreased as far as its relation to the rest of the circuit is concerned, but this may be completely accomplished by removing the condenser from the filament lead entirely, leaving but one connection from the closed oscillatory circuit, and this direct to the grid. The circuit will function as before though the signal amplification obtainable is not to be compared with that of the circuits shown in Figures 14, 16 and 17 of the paper under discussion.