How to Build a Six-Tube Second-Harmonic Super-Heterodyne

Whose B-Battery Consumption is Exceptionally Low—A Set for the Constructor Interested in Efficiency and Economy

By ALLAN T. HANSCOM

FOR some time we have been looking for a super-heterodyne which required fewer tubes and was more economical to operate than those we have described heretofore. Mr. Hanscom brought one of his six-tube receivers to our laboratory and demonstrated its superiority to our entire satisfaction. It is easy to tune, selective, sensitive, and produces exceptional volume with clarity far above the ordinary.

This receiver, because it is necessary to make rather than purchase some of the coils, is somewhat more difficult to construct than those standardized receivers we have previously described. Receivers of this type are going to improve beyond our powers of imagination and this improvement is indicated very clearly in Mr. Hanscom's work, which we feel is a long step in the right direction.—THE EDITOR.

THE purpose of this article is to outline the theory of operation and to describe in detail the construction of a receiver that can be built successfully by the fans who like to make their own sets.

There are several types of super-heterodynes available, and in most cases the results are accomplished by using eight tubes or more, with corresponding large drain on A and B batteries. This is the factor that has caused the super-heterodyne to be called the "Rolls-Royce." The receiver performs excellently but at exceedingly high first cost and high maintenance.

The super-heterodyne designed by the writer is not an expensive set to build, it is not a freak, and it will bring in all stations that any good set will with a B-battery consumption of less than fifteen milliamperes using 201-A tubes and an eighteen-inch loop. When we consider that commercial types of five-tube neutrodynes draw about twenty milliamperes from the B battery, it is apparent that this super-heterodyne is not an expensive set to maintain.

The biggest advantage that a super-heterodyne has is its ability to operate on a loop. A good set of this type will positively get down to the sound level of the atmospheric electrical disturbances when using a loop, and it is therefore of no advantage to use an outdoor antenna. A poor super-heterodyne, with a low factor of amplification, will work better on an antenna, but so will any type of set, for that matter.

WHAT A SUPER WILL DO

WHAT you will hear with a super-heterodyne is exactly what you will hear with any good set, except that the directional effect of the loop will prevent some interference and the ease of tuning makes the stations easier to obtain. A super-heterodyne will not amplify a signal if the signal isn't there. By that I mean that a broadcasting station a thousand miles away cannot be heard unless the carrier wave is stronger than the static disturbances *when it reaches the receiving set.* But for the ability to go out and get a lot of stations quickly and easily when conditions are right, the super-heterodyne can't be surpassed.

Radiation, sometimes incorrectly called "re-radiation" is a fault of many super-heterodynes. In general, any circuit which has an oscillating vacuum tube coupled to a loop becomes a miniature transmitter. This condition is greatly aggravated by the use of

FIG. 1

a large antenna. The super-heterodyne described herein does not radiate because the oscillator isn't coupled to the loop. In addition, the oscillator frequency is nowhere near the frequency of the received signal, because the principle of the "second harmonic" is used.

ADVANTAGES OF THIS SUPER

AT THIS point it may be well to consider the essential parts of the super-heterodyne as shown by Fig. 1.

The only reason for this type of set is the fact that it is better to amplify on the long waves than at the usual broadcasting frequencies. Assuming a 300-meter wavelength which has a frequency of 1,000,000 cycles per second, the super-heterodyne changes this frequency to the exact value that will pass through the long-wave amplifier (see Fig. 1). The frequency of this long-wave amplifier is not variable, and because it is in the neighborhood of 40,000 cycles per second, the amplification per stage is very high. Because the amplifier is designed to pass only a narrow band of frequencies, the selectivity is also high.

The manner of creating this new low frequency is a puzzle to many people, but it is accomplished by a combination of the signal frequency with a new frequency which is generated within the set. Arithmetically, the case is as follows: Assuming the incoming carrier wave with a frequency of 1,000,000 cycles, if we generate a frequency in the set of 1,040,000 cycles, the difference between the two will be 40,000 cycles. If the generated frequency is 960,000 cycles, the difference between that and 1,000,000 cycles is still 40,000. Because the two frequencies are combined, the resultant frequency is the difference between the two. There is also a frequency equal to the sum of the two, but this is not utilized.

PRINCIPLE OF THE SECOND HARMONIC

ANY frequency has certain harmonics. By this we mean that a frequency double or triple the original will bear a certain fixed relation to it at all times. If we assume the case of a man and a small boy walking up the street together, the man may be taking strides of exactly thirty inches. Now, if the boy is taking two steps to the man's one, and the boy's steps are exactly fifteen inches, then they

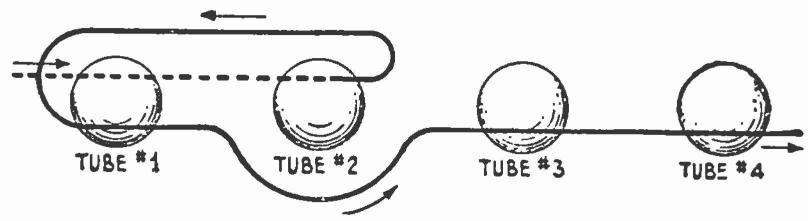


FIG. 2

will always be in line. In this case the man's step is the second harmonic of the boy's step.

In applying this principle to the super-heterdyne, the arithmetic gives us this:

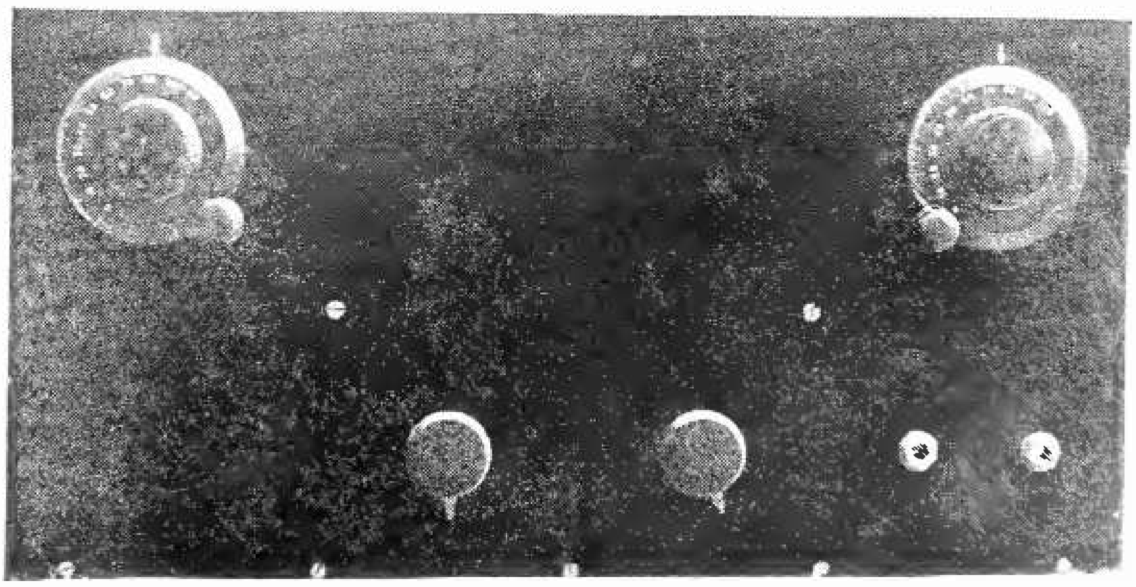
Incoming signal . . .	1,000,000 cycles
Second harmonic of this .	500,000 "
Generated frequency . .	480,000 "
The difference	20,000 "

But 20,000 cycles is the second harmonic of 40,000 cycles, which is the frequency of the long-wave amplifier. By this method we generate a frequency in the set which is so different from the signal frequency that for practical purposes it is entirely independent of it.

It must be understood that the amplifier frequency does not have to be exactly 40,000 cycles. The lower this value is, the closer it approaches the audible frequencies, which extend up to about 12,000, while as it goes higher, the problem of amplification becomes more difficult.

Fig. 2 shows the path of the signal through the first four tubes. The dotted lines represent the frequency of the received signal, the solid line shows the amplifier frequency.

The incoming signal is amplified at radio



THE FRONT OF THE PANEL
Extreme simplicity of control is a notable feature of this receiver

frequency by tube No. 1, and passed into tube No. 2. This tube is oscillating and generating a frequency which combines with that of the incoming signal to produce a new low frequency which is fed back into tube No. 1 and amplified. This is known as reflexing. From No. 1 the output now goes to No. 3, where it is again amplified and then detected by tube No. 4.

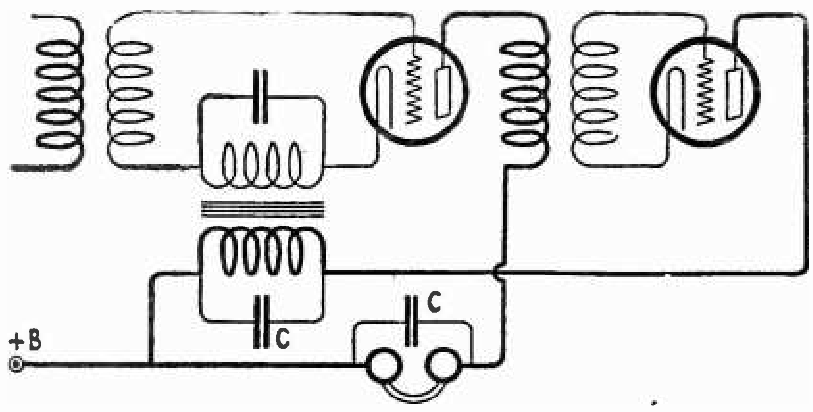


FIG. 3

ABOUT REFLEXING

WHAT are known as reflex receivers are those in which the audio frequencies are fed back through the tubes which are already amplifying radio frequencies. In this type of super-heterodyne, the audio frequencies are not reflexed, but the same conditions apply.

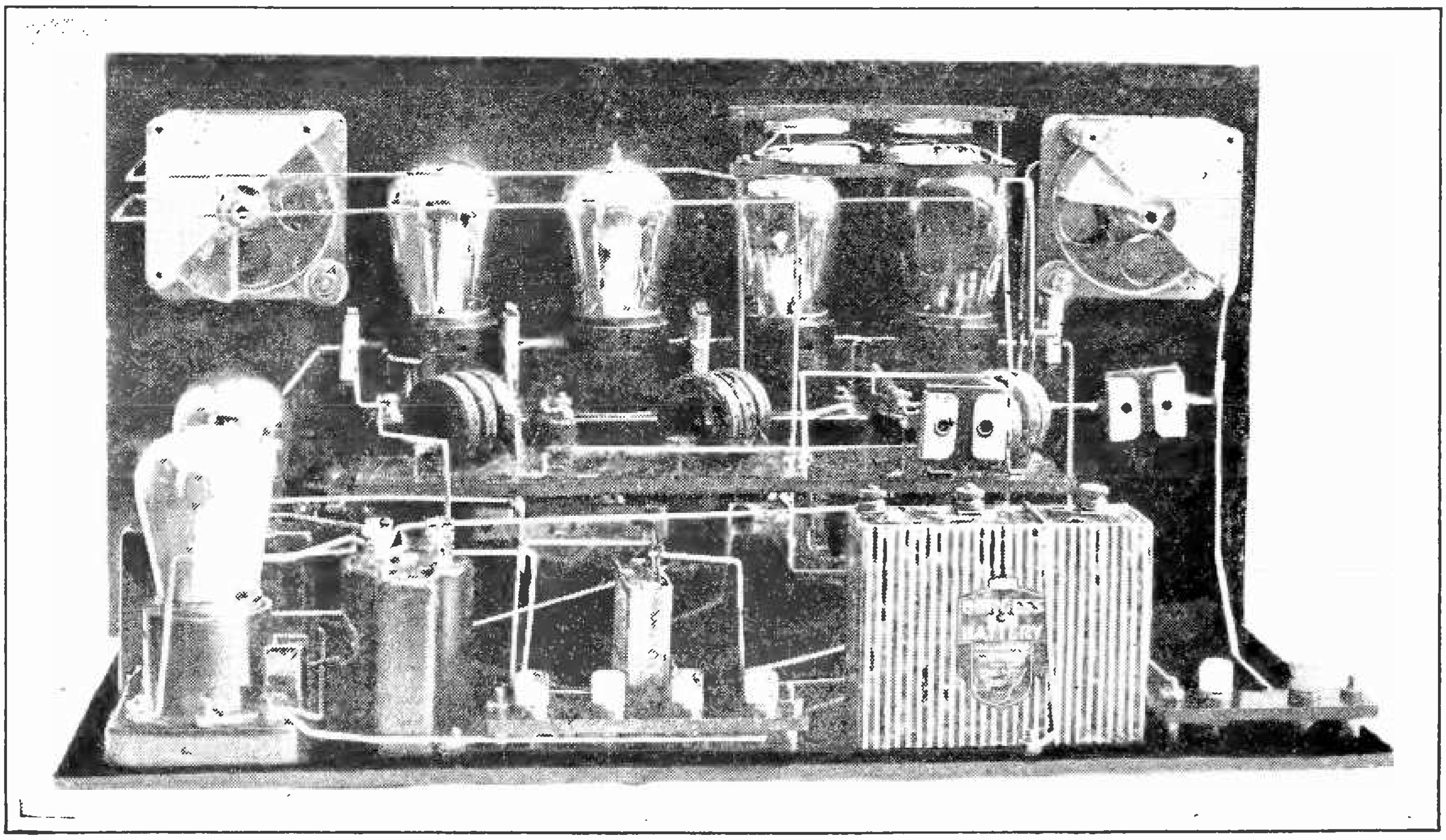
It is obvious that a tube may be reflexed for both radio and audio frequencies, but the intermediate frequency which is utilized in the super-heterodyne must necessarily be above audibility.

Fig. 3 represents a typical reflexing arrangement where the fixed condensers are used to bypass the radio frequencies. Most people do not realize that the shortest path for radio frequencies is the best path. This is shown in Fig. 4, which is exactly the same as Fig. 3 except that the radio frequencies are bypassed directly back to the filament.

As will be seen in the circuit diagram, the first tube acts as a radio-frequency amplifier while the second tube is an oscillator and detector. The output of the second tube consists of three frequencies: first, the frequency of the incoming signal; second, the frequency of the oscillator; and third, the beat frequency, which is the difference between the other two.

The higher frequencies are bypassed back to the filament of the oscillator tube but the beat frequency is fed into the primary of the first intermediate-frequency transformer. The secondary of this transformer is connected in the manner indicated by Fig. 5 which is done in order to neutralize the tube capacity which is accomplished by means of the neutralizing condenser N.

The coils A, Fig. 5, are the secondary of an intermediate-frequency transformer. If they are equal and the condensers C are equal, then the tube is neutralized, provided the condenser N is equal to the grid-plate capacity



REAR VIEW

Of the receiver, showing the method of mounting the fixed condensers between the tube sockets of the tube. The high-frequency voltage from the loop cannot pass a current through the coil A, because of its high impedance, and the low-frequency voltage generated in A cannot pass a current through the loop because of the condenser C in series with the loop. And because the first tube is neutralized, it cannot oscillate and no potentiometer is required.

AIR-CORE TRANSFORMERS

MANY super-heterodynes use transformers with iron cores, and in most cases they use one sharply tuned transformer or filter to make the intermediate frequency sharp enough for good selectivity. The disadvantage is that the iron-core transformers are not as efficient, but the difficulty with the air-core transformers has been that the tuning is apt to be too sharp. This has been overcome in the set pictured by a special design of coils with a provision for moving the coils to tune each stage for the most efficient amplification. By this means great selectivity is obtained as well as great amplification with an absence of the hissing sound which is so prevalent in some super-heterodynes.

As might be expected, the tuning of the set is very sharp. A 500-watt station ten miles away can be completely tuned out in less than one point on the oscillator scale. The dial readings are always the same for the same station, and with the proper number of turns in the loop the settings of both condensers are approximately the same for any particular wavelength.

HOW TO BUILD THE SET

WITH the foregoing explanations, the circuit diagram, Fig. 6, may be easily understood. It is not essential that the apparatus be mounted as closely as shown in the photographs, but it is absolutely necessary to keep all grid and plate leads as short as possible and remember that the fixed condensers are bypassing objectionable radio frequencies *back to the tube where they come from. Keep these condenser wires short and direct.*

The materials needed are as follows:

1 Panel 9" x 18" x $\frac{3}{16}$" (Don't use wood)
1 Panel 8" x 18" x $\frac{3}{16}$" (Don't use wood)
1 Panel 4" x 10" x $\frac{3}{16}$"
3 Hard rubber strips—$\frac{1}{4}$" wide, $\frac{3}{16}$" thick, 2" long
5 Hard rubber strips—1" wide, $\frac{3}{16}$" thick
  3 4" long (2 for oscillator, 1 for terminals)
  2 3" long (1 for oscillator, 1 for loop terminals)
6 Sockets—Composition, not metal
2 Jacks—1 double circuit, 1 single circuit
2 Rheostats—1 6 ohms, 1 30 ohms, any good make
2 Variable condensers—.0005 mfd.—Any good make with vernier dials or knobs (not separate vernier plates)
7 Fixed Condensers—2 .0005 mfd. 2 .00025 mfd. 3 .002 mfd.
1 Grid leak and condenser combined, .00025 mfd. and from 2 to 5 megohms.
2 Audio-frequency transformers—(low ratio)
6 Binding posts
  Square tinned bus bar, $\frac{6}{32}$ screws and nuts, etc.
9 Coils for intermediate-frequency transformers
4 Coils for oscillator
1 Dubilier Duratran radio-frequency transformer
1 Neutralizing condenser
1 Bypass condenser, 1 mfd.

The first step in the construction of the set is the assembly of four sockets on the 4" x 10" rubber panel as indicated in Fig. 7. After mounting the sockets the $-$F connections are joined with bus bar and the $+$F connections of tubes 1, 2, and 4 counting from the left are joined. This is shown in the photograph of the top view of the set.

The next consideration is the intermediate-frequency transformers. Each transformer is made of three small honeycomb coils which are clamped on the rubber panel by strips of hard rubber and small screws. The center coil is the primary and the two outside coils form the secondary. The coils are mounted at an angle of 55 degrees as indicated in Fig. 7 with a space of about $\frac{1}{16}$" between adjacent coils. By loosening the screws which hold the small hard rubber strips, the coils may be moved endwise for accurate tuning after the set is finished.

It is very important that the wires from the coils be connected in the right direction. The inner ends of the two outside coils are connected and the coils are mounted so that the outer ends of these two coils face

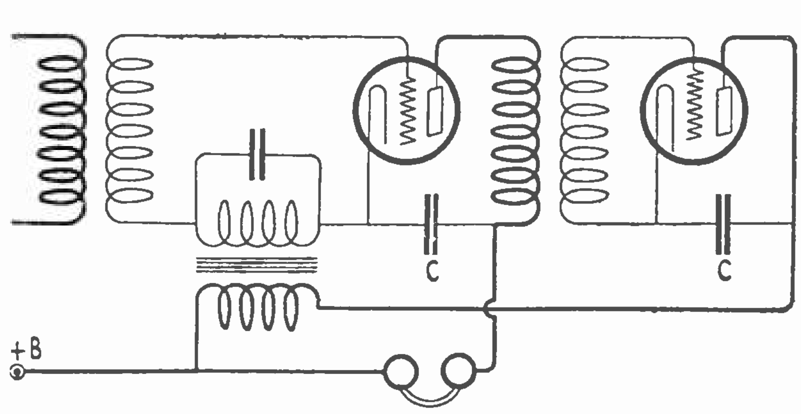


FIG. 4

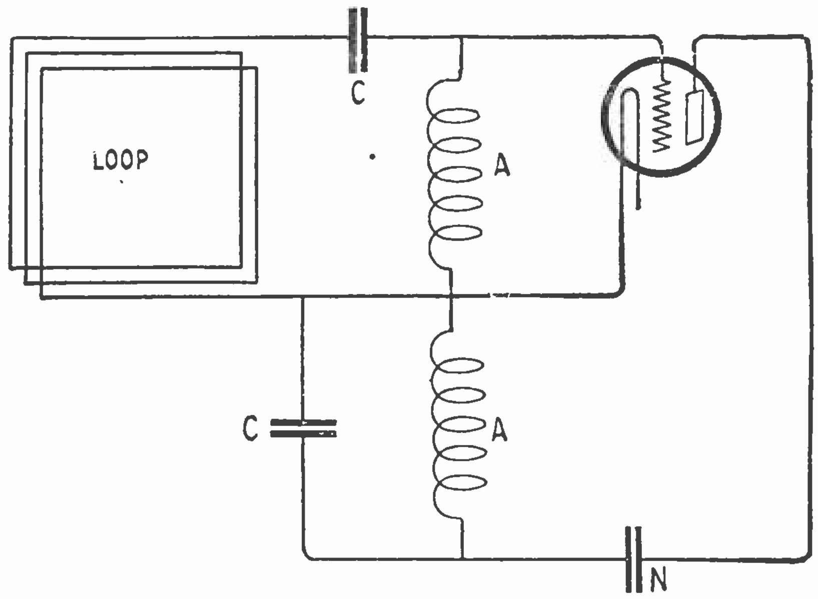


FIG. 5

in opposite directions. Looking at the end of the coils, if the wire runs clockwise starting at the outside of the first coil, it must continue to run clockwise starting at the inner end of the coil in series with it. See Fig. 8. The center coil, which is the primary, may be mounted either way.

After this, the Dubilier transformer is mounted midway between sockets 1 and 2 on the *under side* of the panel with the −F and +B connections at the rear. Then the grid leak is mounted on the under side of the panel near the grid connection of socket No. 4. At this point it is optional whether the mounted parts are wired or the wiring left until the socket assembly is fastened to the front panel.

The photographs clearly show the arrangement of parts on the front panel (9″ x 18″) and the base panel (8″ x 18″). Owing to the different parts which may be used, it is not possible to give absolute dimensions. Looking at the front view of the set, the left-hand dial tunes the loop and the right-hand dial tunes the oscillator. The left-hand lower knob is the rheostat which controls all the tubes and the right-hand lower knob is the 30-ohm rheostat which controls the filament of the third tube for the regulation of the volume. It is suggested that the audio stages be wired before the base panel is joined to the front panel, although this is not absolutely necessary.

The bus bar may be rigidly secured to the sub panel by boring a small hole and bending it as in Fig. 8A.

In soldering, use only resin-core solder.

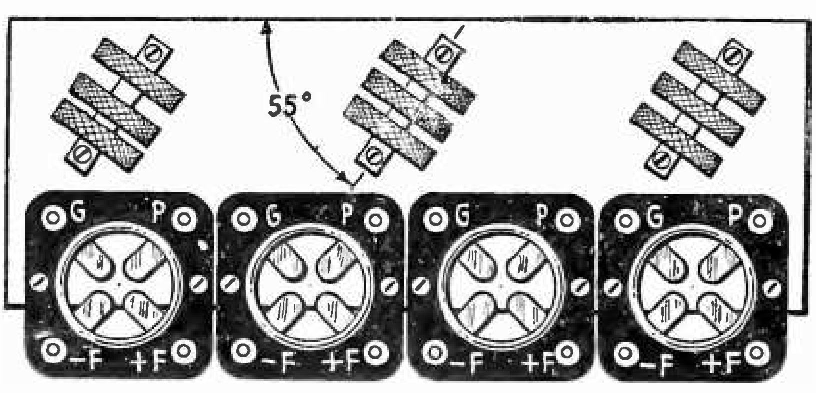


FIG. 7

If panel-mount sockets are used, it is possible to fasten the four-tube assembly to the front panel of the set by using the socket mountings, otherwise use brass angle irons. In fastening the front panel to the base panel, it is possible to drill the edge of the base panel and tap for $\frac{4}{36}$ machine screws, but this may also be avoided by using brass angle irons.

The variable condensers should be connected

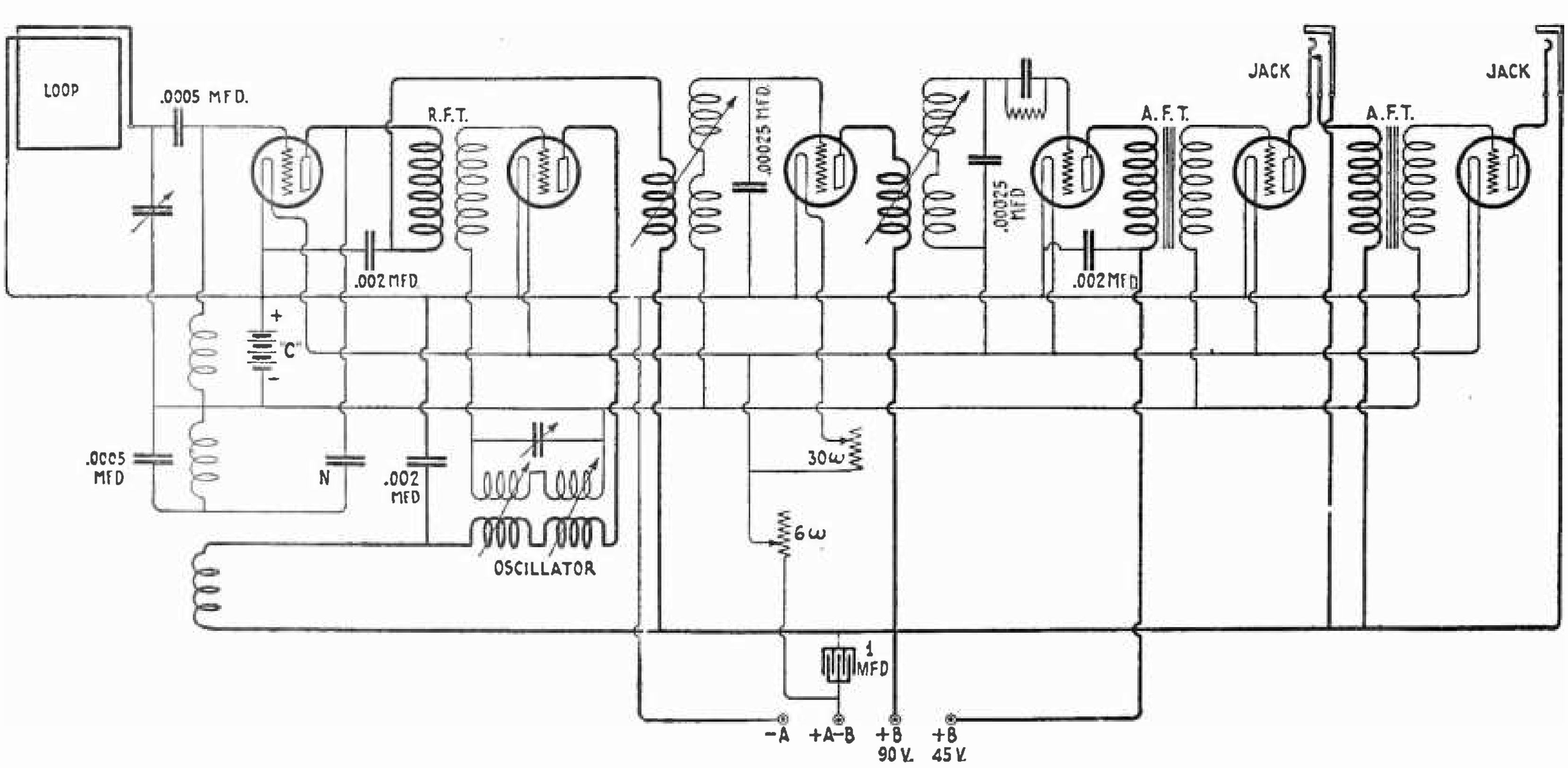


FIG. 6
Complete diagram of the six-tube super-heterodyne

so that the fixed plates go to the grids of the tubes and the movable plates are connected to the C-battery negative.

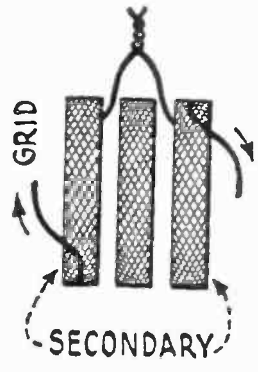


FIG. 8

To avoid errors, it is an excellent plan to draw over the wiring diagram with a colored pencil as each wire is connected.

The C battery is fastened to the base panel with a piece of bus bar as shown in the photographs.

NEUTRALIZING THE FIRST TUBE

IT WILL be seen from the photographs that the coils in the first intermediate transformer are not evenly spaced. This is because with a fixed value of neutralizing condenser the neutralizing can best be done by moving the coil A in Fig. 9. The value of the neutralizing condenser is about equal to the

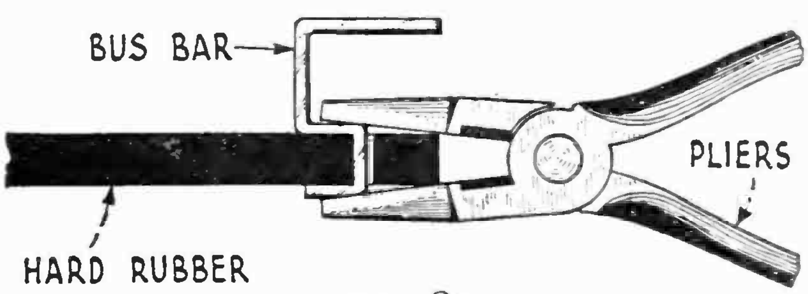
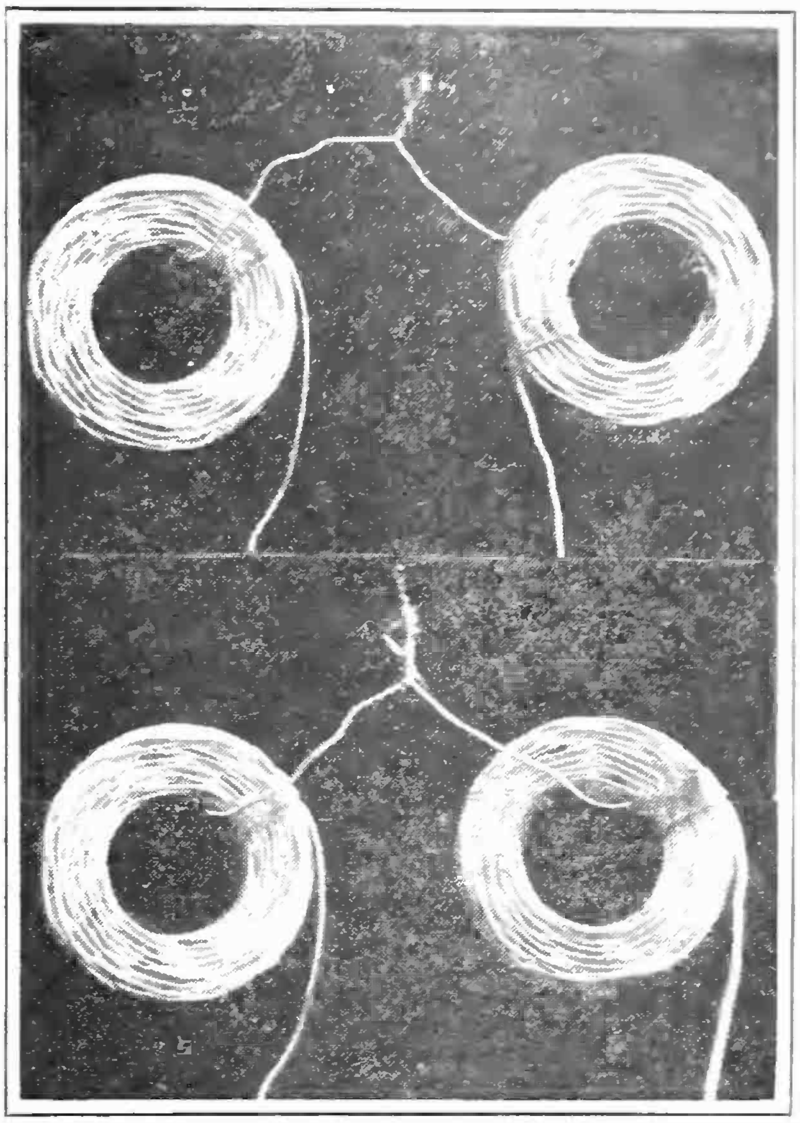


FIG. 8A

full capacity of a neutrodyne condenser when the rod is connected to one terminal and the sleeve to the other. See Fig. 10.

A flexible wire connection may be made to the metal tubing to allow further variation. Once set the position of the metal tubing may be fixed with a drop of wax.

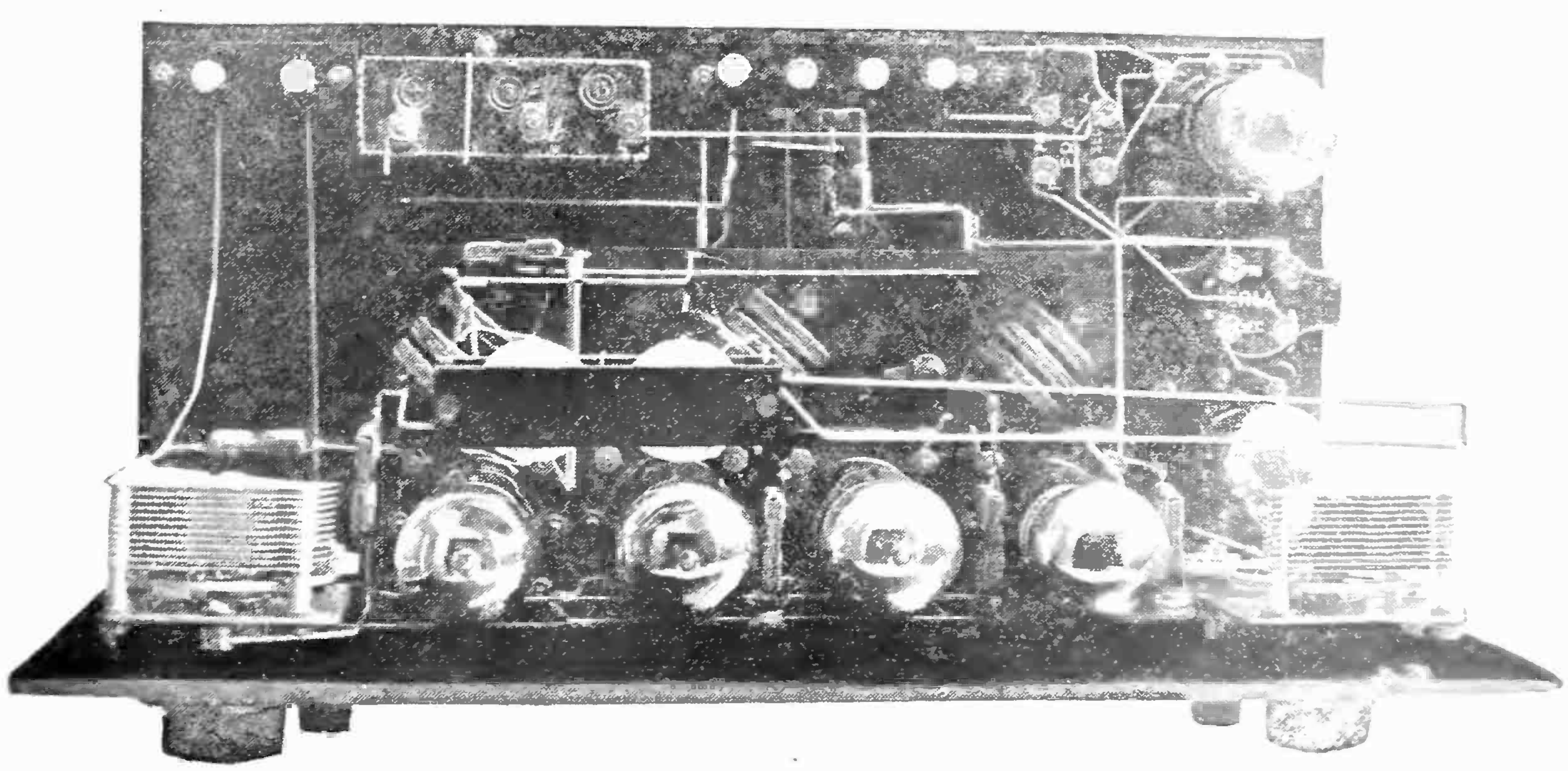


HOW TO MOUNT THE OSCILLATOR COILS

The wrong way is shown at the top of the photograph and the correct way at the lower part of the cut. Both windings should be placed so the wires run in a similar direction

THE OSCILLATOR

THE oscillator is composed of four coils, two in series in the grid circuit and two smaller coils in series in the plate circuit. The manner of connecting these coils is very



TOP VIEW OF THE RECEIVER

Which shows quite clearly the mounting and position of the intermediate transformer and oscillator coils

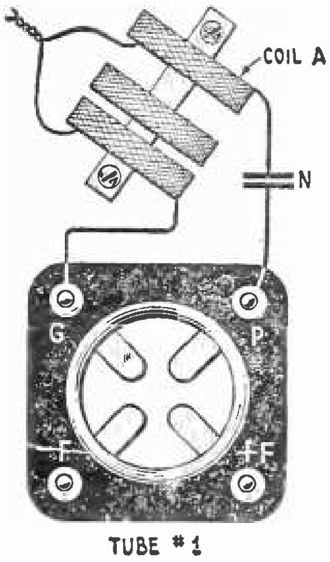


FIG. 9

important, and is indicated in the photographs. They are connected so that the direction of the current if clockwise in one coil will be counterclockwise in the coil in series with it. This is done to provide a closed magnetic field as indicated in Fig. 11.

To make the tube oscillate it is also necessary to place the grid and plate coils together so that the *direction* of *rotation* of the grid wire is opposite to that of the plate wire in the other pair of coils. See Fig. 11.

The manner of mounting the oscillator is clearly shown in the photographs. It is supported by the bus wire leads which are fastened to each corner of the lower rubber strip. The intensity of the oscillations can be varied by changing the thickness of the spacer between the pairs of coils. For best results this should be about $\frac{3}{16}''$.

OPERATING THE SET

AFTER the set is completed and the tubes are in place, connect the A battery and light the tubes. If they light, then turn them off and connect the − B battery to the + A binding post. Then touch the +B wire to the +B binding post. This may spark the first time it is touched because of the capacity of the bypass condenser, but it should not do so more than once. Then the +B 45 may be connected and the set is ready for adjusting. Turn the volume control rheostat full on and then light the tubes to normal. With phones plugged in the last jack, it ought to be possible to tune-in a powerful station after connecting the loop. Oscillation in the first tube may be noted by a series of bird-like whistles as the dials are turned. This may be stopped by moving the coil A, Fig. 9, to the proper point, or by varying the neutralizing condenser. If the set is wired properly, this adjustment is not very critical.

CAUSES OF FAILURE TO OPERATE

AMONG the various causes of trouble in operation of this receiver, some of those most apt to be encountered are:

1—Wrong wiring
2—Faulty tubes
3—Short-circuited fixed condenser
4—Wrong polarity on C battery.

It will be found that a station can be tuned-in at several places on the oscillator dial, but it is usually heard best at a setting about the same as the setting of the loop-tuning dial, provided the loop is of a value that will bring a 360-meter station at about 35 on the condenser scale.

THE LOOP

WITH the various loops now on the market, it is easier to buy one ready made than to make one, although a suitable loop can be made of single lamp cord (stranded) of 13 or 14 turns on a frame 18 inches square, with the turns spaced from $\frac{1}{4}$ to $\frac{3}{8}''$ apart.

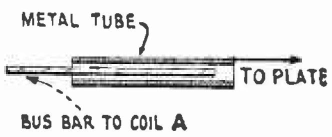


FIG. 10

Don't use fine wire and green wood. The larger the loop, the fewer the turns for a given wavelength and the greater the signal strength. The writer has used a variometer for a loop on stations 200 miles away with enough intensity to operate a loud speaker, but don't penalize the set with a poor loop. Get a loud signal and then control it with the rheostats.

A HINT TO HOME CONSTRUCTORS

DON'T solder lugs on the end of bus bar when it is going to be connected to terminals on sockets or transformers. It is far better to invest in a pair of round-nosed pliers and bend an eye on the end of the bus bar. Don't screw down the terminals with your fingers, because they will not stay tight. Use pliers or a wrench.

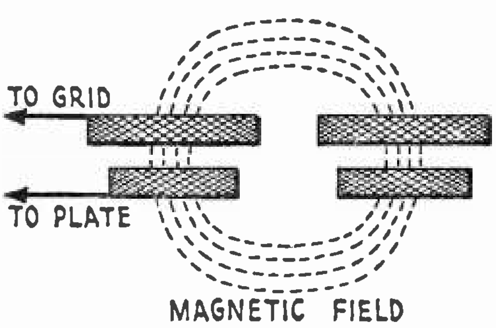
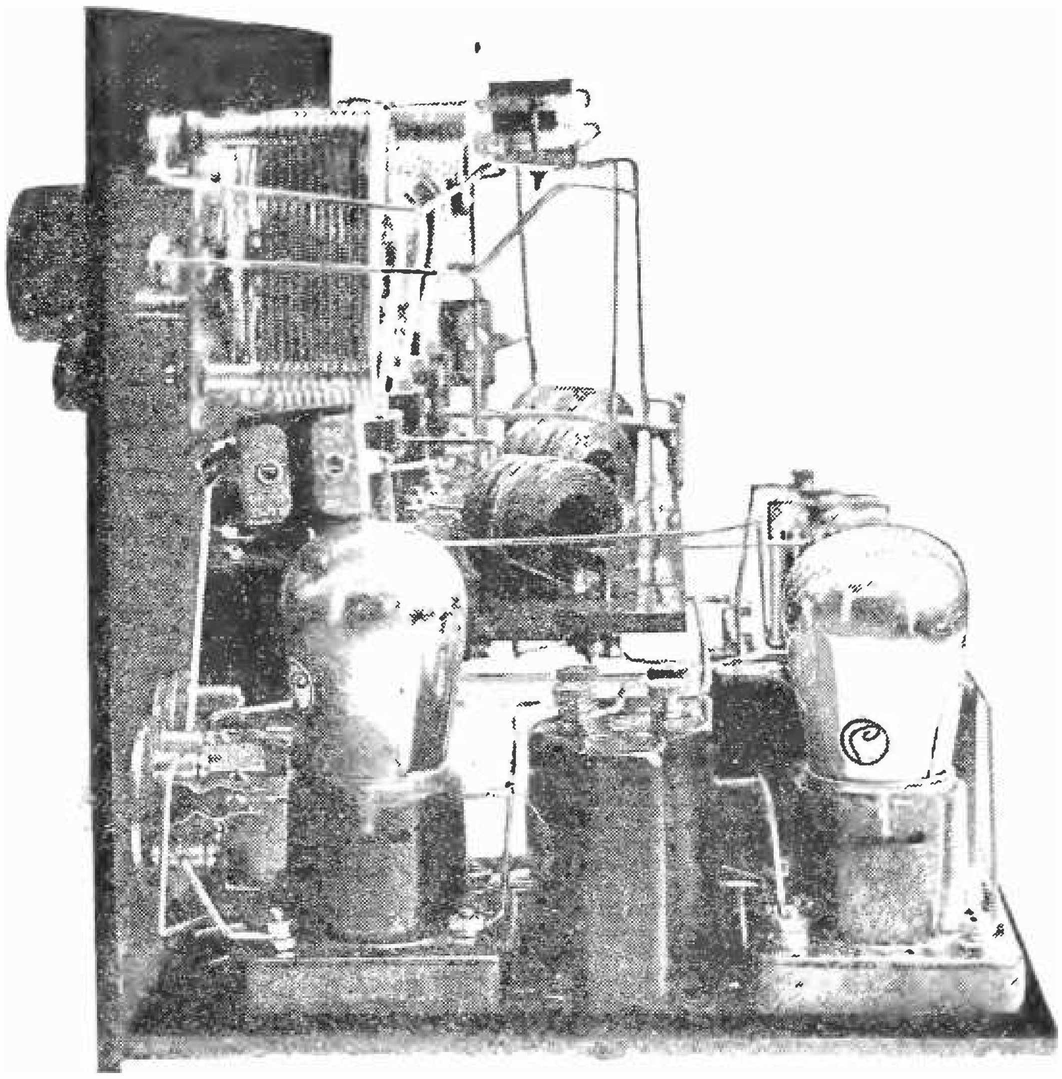


FIG. 11

A TEST PERFORMANCE

IN OUR laboratory in Garden City we were able to bring in Philadelphia and Schenectady in daylight with good loud speaker volume, using this set and a small loop and *five* tubes in *daylight*.

During two tests made at night, each of two hours duration, using five tubes and a loud speaker, the following stations were logged. The dial settings were as indicated, and may be generally helpful to those who duplicate the receiver just described. Some idea of the selectivity of this receiver may be had by noting the number of stations logged between WEAF and WJZ, both of which are less than twenty miles from Garden City. Both were operating most of the time during which the four distant stations were logged.



SIDE VIEW
Showing the output end of the set

LIST OF STATIONS HEARD

CALL	DIAL SETTINGS LOOP	OSCILLATOR	WAVE LENGTH
WNYC	78	83	526
WIP	75	81	509
WEAF	66	73	492
WHAA	65	88	484
WOC	64	71	484
WDAF	63	69	411
WCAP	59	66	469
WJZ	55	62	455
WSB	51	52	429
WLW	48	64	309
CFCA	48	54	400
WTAM	41	65	390
WGY	39	50	380
WMAF	38	42	360
WEBH	37	42	370
WJAR	33	37	360
WLS	32	35	345
WHN	32	38	360
WCBD	32	36	345
WBZ	30	34	337
KDKA	28	32	326
WTAS	22	26	286

Many stations not included in this list were heard but were not logged because call letters were not heard. It is to be noted that most of the stations on this list are not local.

This particular receiver we used is not a freak. We have tried two, and Mr. Hanscom has made several others. They all have the same characteristics.

We were so favorably impressed with this new departure in storage battery tube outfits that we contemplate using one at the temporary receiving station we are going to equip somewhere on the coast of Long Island for our International broadcasting tests. Another receiver of this type will be used by Mr. Hanscom at his home in Woonsocket, Rhode Island, for the same purpose, and he will arrange to report reception directly to our Garden City Laboratory.—THE EDITOR.