about two years ago. with the remark: "The trouble with these sets was, that it required a millionaire to buy and operate them. The average man's income was not enough to support a super-heterodyne."

Making the Super-Heterodyne Practicable

With the advent of dry battery tubes and storage battery tubes using low filament current, the problem of bringing the super-heterodyne down within means of the average man was somewhat simplified. But it was too much to expect dry cells to supply nine tubes with filament current. Besides, the construction was still too costly. There was undoubtedly need for having some of the tubes do double duty. The most practicable step was to combine the radio frequency oscillator with the first detector, i. e., employ the self-heterodyne effect. The trouble with this, however, was that on adjusting the frequency of the oscillating circuit portion. we are likely to detune the receiving circuit, and vice versa, because the two frequencies are so close. Such a system is all right for receiving telegraph signals, where the beat may be made a fairly high audible note; but in receiving telephony and music, we must make this beat frequency above audibility—and keep it there. Probably the most suitable region is in the neighborhood of 50,000 cycles per second. In the super-heterodyne receiver, if the self-heterodyne were adjusted to give a beat note of 50,000 cycles, the receiving circuit would be detuned to so great an extent from the frequency of the station it is desired to receive, that the results would be worthless. Besides, any minute change in the adjustment of one would react on the other.

After three years of experimentation in an effort to discover a means of combining the first detector and oscillator, a solution was at last found. A great share of credit for this discovery belongs to Mr. Harry Houck, who has been Armstrong's able assistant all these years. It is well known to all who have worked with radio, or for that matter, audio frequency oscillators, that if the circuits are adjusted so as to secure a given frequency, we not only obtain the frequency, but also a whole series of others, which are exact multiples of it. If, for example, the oscillator is tuned to 275,000 cycles per second, we will in addition get the following frequencies: 550,000 cycles, 825,000 cycles, 1,100,000 cycles. etc., etc., which are called second, third, fourth, etc., harmonics, respectively; these harmonics correspond to two, three and four times the fundamental frequency of 275,000 cycles. This production of harmonics is due to certain assymetrical characteristics of the vacuum tube and is not at all difficult to understand.

It is precisely similar to the production of overtones in musical instruments—where, when a certain note is sounded, we have present, not only the fundamental tone, but also a whole series of harmonics or overtones, which give the instrument in question its peculiar characteristics by which we recognize it. At any rate, in the super-heterodyne receiver, in combining the detector and oscillator, we have the oscillator work at some frequency below that which we desire to receive and select the second harmonic to produce the beat note. Thus, if the loop in figure 2 is tuned to say 600,000 cycles (500 meters), the oscillating circuit is adjusted to 275.000 cycles. The second harmonic of the oscillator is 550,000 cycles, which on heterodyning with the received 600,000 cycles, will give a beat note in the detector of 50,000 cycles. The local oscillator may also be tuned to 325,000 cycles, the second harmonic of which is 650,000 cycles—and the resulting beat note is also 50,000 cycles. Thus we will obtain results at two different tuning points of the oscillator in the super-heterodyne receiver. The frequency of the oscillator is so far from that of the incoming frequency, that there is no noticeable change in the tuning of one, when the other is adjusted. This is but one of the steps in the gradual reduction of the nine-tube outfit.

The next step in compressing the set to reasonable proportions was in the reflexing of the radio frequency amplifier with the intermediate frequency amplifier. The method involved here is illustrated in figure 3. The incoming oscillations are picked up on a small loop, which may be so small that it is readily concealed within the box containing the receiver. These are applied to the grid of the first tube through a condenser of .0001 microfarad capacity, which does not oppose the flow of currents of high frequency. These oscillations are amplified by the tube and then applied to the grid of the detector and oscillator tube (the second tube) by means of an ordinary radio frequency transformer. Note that no grid condenser or grid leak is required here, since we are detecting a frequency which is extremely high, and must rely on the curvature of the grid current and plate current curves in order to produce rectification, rather than on the action of the discharge of a grid condenser through a very high resistance.

The second tube also functions as an oscillator, which is tuned to a little less (or a little more) than half the frequency of the incoming signals. The beat note which results between the second harmonic of the locally generated oscillations and the received oscillations is obtained in the process of detection. This beat note, which is in the neighborhood of 50.000 cycles, is passed through the primary winding of an intermediate frequency amplifying transformer, the secondary of which is in the grid circuit of the first tube, which is also the radio frequency amplifier. A condenser of .0001 mfd. capacity, or even less, is connected in the grid circuit as shown, so that the secondary winding will not be short circuited by the loop circuit. In series

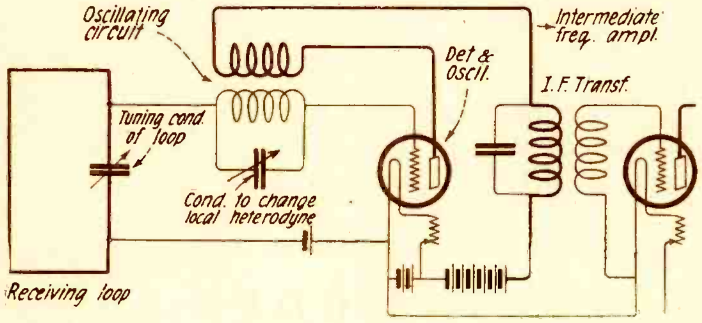

Figure 2—Application of principle of self-heterodyne to super-heterodyne

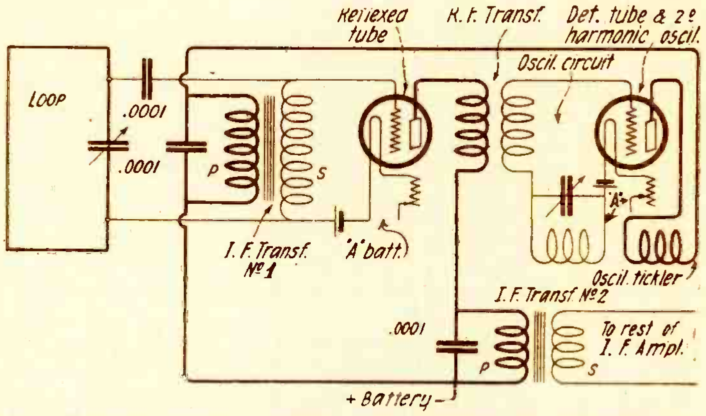

Figure 3—Principle involved in reflexing radio frequency and intermediate frequency amplifier and in using detector as second harmonic oscillator

with the radio frequency transformer in the plate circuit is connected another I. F. (abbreviation for "Intermediate Frequency") transformer, the secondary of which leads to the rest of the I. F. amplifier, which is made in the usual manner and has been described several times in past issues of THE WIRELESS AGE. The .0001 microfarad condensers shunting the primary windings of the I. F. transformers are inserted in order to allow the comparatively high radio frequencies to by-pass the high inductance windings of the I. F. transformers. No filament or B batteries are indicated in the diagram—but these are connected in the usual manner.

With such combinations as these, Major Armstrong was able to reduce the original super-heterodyne to six dry cell tubes—and obtain even better results than with the nine storage battery tubes used previously. He then pointed out a number of such receivers, built within the past year, of surprisingly small dimensions. A box, about 6 inches by 8 inches by 20 inches, using six UV-199 Radiotrons was complete in every respect; it contained a loop, A-batteries, B-batteries, C-batteries, to say nothing of the super-heterodyne equipment itself, such as tuning condensers, transformers, oscillator coils, etc. It was with such equipment that that old lady received stations 3,000 miles distant!

This did not mark the end of the development. It was only the beginning! Mr. David Sarnoff, Vice-President and General Manager of the Radio Corporation, visualized its importance and immediately concentrated the forces of the Research Laboratories of the Radio Corporation, General Electric Co. and Westinghouse Co. on continual day and night work for almost a year. And the result was the finest job in radio engineering that has ever been done. Major Armstrong pointed with no little pride to a number of beautiful cabinets, which housed the new line of super-heterodyne receivers, now being marketed by the Radio Corporation of America and embodying his new discoveries described above.

In regard to selectivity, sensitivity and ease of tuning, they are without peer; local stations do not interfere at all with reception of far distant ones; only two controls are required for tuning, one for the loop and the other for the "second-harmonic" oscillator, the principle of which is illustrated in figure 3. The intermediate frequency amplifier is adjusted at the factory and sealed up, so that the set is not only simple, in its controls, but absolutely fool-proof. The only limit apparently to its sensitivity in receiving distance is *static*. Major Armstrong stated that the average inexperienced broadcast listener can easily receive from stations 3,000 miles away, any time atmospheric conditions are right, when using the super-heterodyne.

With a few brief words, promising new developments for the future, Major Armstrong relinquished the floor. Professor Pupin, in the discussion, took occasion to compliment the speaker for his manliness in giving credit, where due, to his associates and then pointed out that we had already outstripped European nations in scientific development because of our diligent application to research work, both in the universities and in our large industries. In the case of radio, there is no doubt of it at all. At the close of the meeting, little groups of the members of the Institute gathered round the various receivers on display and listened to broadcasting from stations more than 1,000 miles distant, while WJZ, only a quarter of a mile away, was going full blast—and came away convinced of the undoubted superiority of the new super-heterodyne over any other receiver that has hitherto been produced.

More About Inductance Coils

Editor, WIRELESS AGE,

Dear Sir:

I read with interest Mr. Miller's article on "How to Design Inductance Coils," in the February issue of THE WIRELESS AGE.

I would like to suggest the following method as being more direct in the calculation of single-layer coils from Professor Hazeltine's formula:

$$L = \frac{0.0002\ N^2 A^2}{3A + 9B + 10C}$$

Data given:
L = 0.08 milli-henries.
A = 2 inches; 10C is negligible.
Size of wire, No. 22 D. S. C.

Substituting:

$$0.08 = \frac{0.0002 \times 2^2 \times N^2}{(3x2) + 9B}$$

The total number of turns, N, divided by the number of turns per inch is equal to the axial length, B. The number of turns per inch of No. 22 D.S.C. wire is 32 (see table II, page 56).

Then $B = N/32$

Substituting in above:

$$0.08 = \frac{0.0002 \times 2^2 \times N^2}{(3 \times 2) + \frac{9N}{32}}$$

Simplifying: $N^2 - 28N - 600 = 0$.

Solving the above quadratic:

$N = 43$ turns.

Very truly yours.

Manchester, N. H. A. H. CASTOR.

Latest Radio Developments

WHEN asked if the average broadcast listener could build the set, Major Armstrong said that the second harmonic super-heterodyne is a piece of apparatus which can be built only by an experienced radio engineer and that the exact dimensions of each wire and part must be known.

He said: "Radio sets are likely to become more complicated year by year and to give a person a copy of the super-heterodyne circuit and detailed instructions relative to construction would be like giving the average mechanic a complete set of blueprints of an automobile. Efficient and complex radio sets of the future will not be home-made any more than the automobile. It will be less expensive and results will be far more satisfactory if the set is purchased complete. I should not advise any one to attempt to build a home-made super-heterodyne operating on the second harmonic principle because I know the results would be extremely disappointing."

Dr. Alfred N. Goldsmith, head of the RCA Research Laboratory, said: "The set cannot be built by the average radio follower. It consists of a heavy casting called a catacomb box in which shelves are arranged for mounting the apparatus. All of the parts are mounted and then the catacomb is filled with wax, making the set practically a solid block. The instruments are so designed that they will not function the same in air as they will in the wax block. This is a new practice in construction of radio sets. If an experimenter took one of the sets apart and attempted to build a duplicate I am afraid he would experience great difficulty. A hook-up or blueprint of the second harmonic super-heterodyne would be about as useful in building the set as a map of Asia."

The slightest deviation from the exact wiring, such as moving a wire a fraction of an inch out of its proper position or making a wire a trifle too long, will change the capacity effect and make the entire circuit inoperative. A slight variation in wiring would cause distortion which, in a single tube set would be unnoticeable, but in a six-tube super-heterodyne outfit this distortion is highly amplified and howls dominate the incoming music.

Dr. Goldsmith said that the ordinary type super-heterodyne receiver, as built experimentally by some radio enthusiasts, using from eight to ten tubes, was difficult to operate and radiated energy continuously, although the operator was not aware that his set was squealing and interfering with his neighbor. With the regenerative circuit the operator can tell when his set is disturbing near-by receiving sets, but in the case of the old type super-heterodyne only the neighbor can tell that the set is howling.

The new set has a new principle called the "regenoflex," and by the use of a special muffler tube circuit radiation from the set is eliminated.—*The New York Times, Sunday, March* 16, 1924.