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The application of permeability tuning to broadcast receivers †

By R. H. LANGLEY*

THE chief difficulty with condenser tuning is that it is inherently incapable of producing uniform performance. By the use of compound couplings it is possible to secure reasonably uniform gain, but no arrangement so far proposed will give uniform selectivity and fidelity except at the expense of a large decrease in the efficiency of each circuit. It was realized as early as 1922 that inductance tuning offered decided advantages in the solution of this problem.

Inductance tuning is a general term for any method in which the total effective inductance in the circuit is varied. The variometer, which enjoyed a considerable vogue in 1922-1924, was a device for securing this variation. The reason it did not succeed was because its resistance varied with frequency in exactly the same way as the resistance of the fixed inductance of the condenser tuned systems, and it was therefore equally incapable of producing uniform performance.

There have been other suggestions for varying the inductance. One proposed to decrease the inductance by introducing a copper shield. The eddy currents in this shield effectively decreased the inductance, but they simultaneously increased the losses and, therefore, the effective resistance, at a rate even greater than in the variometer. Here again there was no possibility of securing uniform performance over the range.

The problem, however, is not to produce a variation of inductance, but to produce a simultaneous and proportional variation of inductance and resistance. The recognition of this fact has come only recently. This is the result secured in the new tuning method which we are examining tonight. It is called "permeability tuning" first to distinguish it from other methods of inductance variation, and second, because this term is adequately descriptive of its mechanism.

With permeability tuning, it is not only possible to secure uniform performance over the broadcast range, or any other range, on all three counts, with a degree of mechanical and electrical simplicity quite beyond anything so far suggested, but other new and valuable results can be secured.

It now becomes necessary to direct attention to a fact which has been too much neglected in the study of the problem of selectivity. The channels on which broadcasting, as well as all other radio services are carried out are equally spaced in frequency. The published mathematical investigations deal exclusively with per cent frequency difference, which has no practical interpretation in terms of actual receiver performance. Even the current statement of selectivity in terms of bandwidth has no physical meaning as an indication of the signals that will be successfully rejected. What we desire to know is not the width of an inverted resonance curve, but just what signal strength, for signals on the channels immediately above and below resonance, can be tolerated without producing audible interference.

The situation with respect to selectivity can be summarized in a diagram, as is shown in Fig. 1.

This diagram represents the performance of five different types of receivers. The horizontal scale in all four graphs is frequency, and the divisions are the actual channels of broadcasting. Graph A is for a tuned radio-frequency receiver in which straight-line capacity condensers are used. The spacing of the channels on the dial of such a receiver will be as shown, that is, very

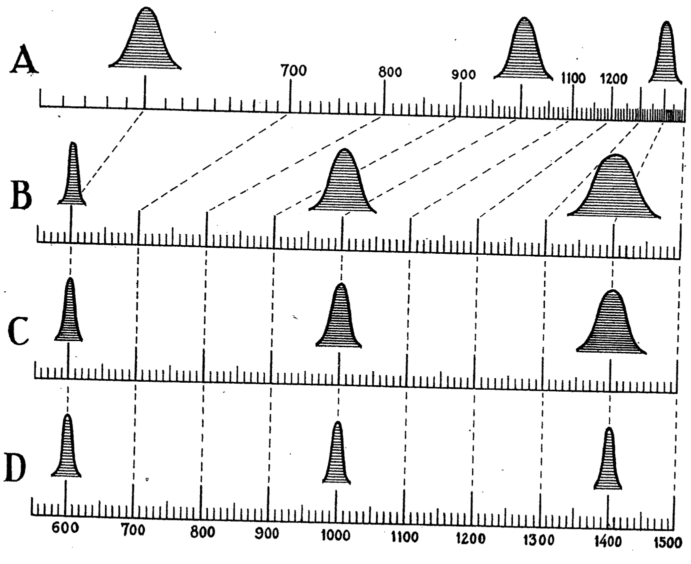

Fig. 1. Selectivity of five types of radio receivers.

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†Presented before the Club, March 9, 1932.

$$\frac{E_r}{E}=\sqrt{K^2+Q^2(K^2-1)^2} \qquad K=\frac{\omega}{\omega_r} \qquad Q=\frac{\omega_r L}{R} \qquad (1)$$

$$k^2+q^2(k^2-1)^2=K^2+Q^2(K^2-1)^2 \qquad (2)$$

$$q=\sqrt{aQ^2+b} \qquad a=\frac{(K^2-1)^2}{(k^2-1)^2} \qquad b=\frac{K^2-k^2}{(k^2-1)^2} \qquad (3)$$

$$\frac{Q}{q}=\frac{\Omega L r}{\omega \ell R} \qquad \frac{Q}{q}=2.73 \qquad \frac{\Omega L}{R}=2.73\frac{\omega \ell}{r} \qquad (4)$$

$$\frac{L}{R}=\frac{\ell}{r} \qquad \frac{\ell}{L}=7.43 \qquad \frac{r}{R}=7.43 \qquad (5)$$

Fig. 2. Selectivity equations.

badly crowded toward the high frequency end. The black curves on this graph represent the apparent width, on the dial, of three signals of equal strength at three different frequencies. Note that, although the actual selectivity of the receiver is much worse at the high frequency end, the *apparent* selectivity is much better at the high frequency end. It shows how completely one fault masked another. It makes clear the fact that the straight line capacity condenser, because it crowded the high frequency channels, completely covered up the glaring fault of the system in which it was used.

Let us now put straight-line-frequency condensers into this receiver. The channels will now be equally spaced on the dial, as in graph B, but the broad tuning at the high frequency end will be strikingly obvious, as indicated by the width of the band covered by the high frequency signal. Such a receiver would meet definite sales resistance because of the lack of apparent selectivity, although the actual selectivity would be the same as in type A, thousands of which were successfully sold. Thus we see the reason the straight-line freceiver condenser, otherwise an entirely logical and desirable improvement, was so slow to find its way into broadcast receivers.

If, by some method not yet suggested, we could arrange so that the actual per cent selectivity, the selectivity of the mathematical treatments, were constant over the frequency range, we should have the situation shown in graph C. Still the apparent selectivity would be noticeably worse at the high frequency end, and so would be the actual selectivity, so far as ability to reject undesired signals is concerned.

Graph D may be taken as representing a superheterodyne receiver, or a properly designed receiver of the permeability-tuned type. In either case the actual channel selectivity is constant over the range. In the superheterodyne, there would be some slight deviation, depending upon the amount of condenser-tuned-radio-frequency amplification employed. In the permeability-tuned receiver there would be substantially no deviation, and, incidentally, it would not be necessary to employ special mechanical arrangements to secure the equal spacing of the channels on the dial. There can, of course, be no question that the performance of graph D is superior to A, B or C, and that it is the ideal result.

To understand why permeability tuning can accomplish this result, with less tubes and fewer tuned circuits than a superheterodyne, it is necessary to examine the mathematics of the situation.

The usual expression for selectivity is given in equation (1), Fig. 2. This states the ratio of the voltages developed across the tuned circuit by a resonant signal and a non-resonant signal, in terms of K which is the ratio of the two frequencies, and Q which is the ratio of the inductive reactance at resonance to the resistance. Q has been called the figure of merit of the circuit. Note that both K and Q vary with frequency.

In order to determine the conditions for constant selectivity, we use small letters to represent quantities at the low frequency end of the range, and large letters for the high frequency end, and we write equation (2) directly from equation (1). Upon simplification this yields equation (3) which gives, implicitly, the ratio which the values of Q, one at the low frequency end, and one at the high frequency end, must have for constant selectivity.

Numerical substitution in equation (3) for the broadcast case, and for the actual 10 kc. separation for the broadcast signals, justifies the writing of equation (4) with the assurance that it is correct, at least to a very close order of approximation. Equation (4) gives the important conclusion that for constant selectivity the ratio of inductance to resistance must remain constant.

In normal condenser tuned circuits, and in inductance tuned circuits of the variometer types, the resistance increases approximately as the square of the frequency. Thus Q (equals omega L over R) decreases as the frequency is increased. If R could be made directly proportional to frequency, then Q would be constant, but even then the selectivity would not be constant, because K, the ratio of the frequencies, is also changing. Selectivity, in terms of actual ability to reject signals on undesired channels, can only be constant over the range when the ratio of inductance to resistance does not change.

In condenser tuned circuits, the inductance is held constant and the resistance increases as the square of the frequency. Such a circuit, therefore, cannot have constant selectivity, except by the expedient of artificially increasing the resistance at the low frequency end. A good tuned circuit has a resistance of about 4 ohms at 550 kc. and 30 ohms at 1,500 kc. If we can contrive to keep the resistance up to 30 ohms throughout the range, then we can have constant selectivity over the range, and it will be just as broad as 550 kc. as it now is at 1,500.

In inductance tuning, the inductance must change inversely as the square of the frequency. For constant selectivity, the resistance must also change inversely as the square of the frequency. This is expressed in equation (5) which states that the resistance and the inductance are to be approximately eight times as large at the low frequency end of the range as they are at the high frequency end.

How can we design a variometer, for use in an inductance tuned circuit, such that the inductance and the resistance will increase together, and their ratio remain constant? By a very simple expedient. We will design our circuit at the high frequency end, at 1,500 kc., to have whatever properties we desire to get, high gain and a high order of selectivity. We will use a relatively small inductance and a relatively large fixed condenser. Naturally both of these will have to be designed so as to have low losses.

Variable Inductance

We will then tune this combination down to 550 kc. by gradually inserting an iron core into the inductance. This will increase both its inductance and its resistance, and we may expect that they will increase together, since both depend upon the amount of iron which is actually inserted in the magnetic field. It will, of course, take a very special form of iron. No form that we have known in the past can be brought anywhere near a tuned radio-frequency circuit without increasing its apparent resistance out of all proportion to the gain in inductance.

Before we examine the material and the core, let us see what some of the other consequences of this method of tuning are going to be. We are not increasing the inductance of the coil itself. What we are doing is to increase the permeability of the surrounding medium. We are actually inserting a new factor in the equation for the frequency of the system. This factor is the effective permeability of the space around

Porcelain	2150 x 10^{12}
Glass	990 x 10^{12}
Bakelite	36 x 10^{12}
Polydoroff iron	50
Carbon (filament)	.004
Nichrome	.000 109
Steel	.000 045 6
Iron (pure)	.000 008 85
Copper	.000 001 589

Fig. 3. Comparative resistivity in ohms per centimenter cube.

the coil. This is the reason for calling the system permeability tuning.

We should assume, from the nature of the method, that if we have two coils of different inductances, but of the same physical dimensions, and if we insert two identical cores into them, the percentage change in inductance would be the same. If we tune these two coils, with different fixed condensers to the same frequency, then as the cores are inserted they should remain in step with each other.

This result can easily be secured, and it has tremendous consequences. It means that for the first time we have a method of tuning the antenna circuit of a broadcast receiver, and keeping it exactly aligned with the other tuned circuits. It means that we can thus secure a gain ahead of the first grid, due to resonance in the antenna circuit, which gives a very noticeable and valuable decrease in the amount of subsequent amplification necessary. But the most important result, so far as the user is concerned, is the marked improvement in the signal-to-noise ratio. This, more than any other feature of the performance of a permeability-tuned receiver, is its outstanding advantage over other present types.

Another result, not quite so obvious, perhaps, is that the frequency to which the system is tuned at any time is almost exactly proportional to the distance to which the core has been removed from the coil. By a slight correction in the shape of the core the relation may be made exact, and this gives, without additional mechanical gear, a uniform or "straight-line-frequency" distribution of the channels on the indicator. Thus the result so difficult to secure with condenser tuning is easily and naturally accomplished in the permeability method.

Since the resistance and the inductance increase at the same rate, an oscillator can be built in which the output is very nearly constant. And, by the use of a series inductance, not affected by the core, such an oscillator can be kept at any desired absolute frequency difference from other tuned circuits on the same uni-control system. Such an oscillator would have wide usefulness in superheterodyne receivers.

If it is desired to build a receiver having two or three ranges, each as wide as the present broadcast range, this can be accomplished by using as many taps on the fixed condensers in each tuned circuit. These taps can be selected by a gang switch without appreciable increase in losses, and the arrangement is mechanically convenient and simple. The ranges in such a receiver will not have quite the same performance, but the difference can be minimized by proper choice of the inductance and the capacity steps. Here, therefore, is a new and simple answer to the problem of an "all-wave" receiver for European service, or for any other service requiring an extremely wide range.

In a condenser tuned system there is a certain minimum capacity, represented by the maximum spacing obtainable between the rotor and the stator, and by the various capacities which exist in the circuits. This minimum capacity determines the value of inductance to be used, since the two together must produce resonance at 1,500 kc. The maximum value of the condenser is thus also determined, since this value taken with the same value of inductance must tune to 550 kc.

With permeability tuning, there is no such limitation. The inductance may have any value desirable to produce the required performance. Whatever the value of the inductance may be, it will be increased approximately eight times by the insertion of the core. Whatever the resonant frequency of coil and condenser may be, it will be decreased to approximately one-third this value, when the core goes into the coil. Thus we really have a new, an independent variable. It is not the inductance of the coil itself that we are varying: it is the effective permeability of the medium surrounding the coil.

When the research to find a form of iron that could be successfully used at radio frequencies was first undertaken, it was appreciated that the task was no small one. In fact, quite a group of scientists had said that it could not be done, and this same statement was repeated after the work was well under way. The core material that we have today is no chance discovery. It is the result of a carefully planned and adequately financed research.

Core Material

Iron sulphate is reduced by hydrogen to a metallic powder. The sulphate is rhombic in crystalline form, the iron cubic. In passing from rhombic to cubic the material must go through atomic or at least molecular dimensions. By proper control of the process it is pos-

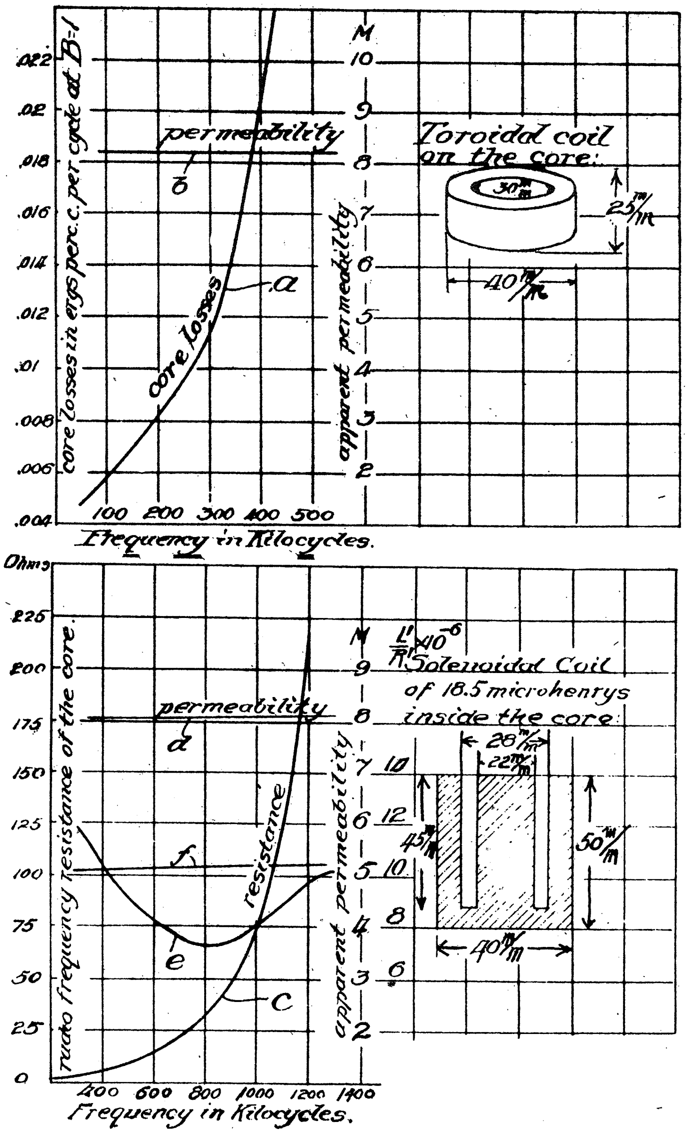


Fig. 4
Characteristics curves.

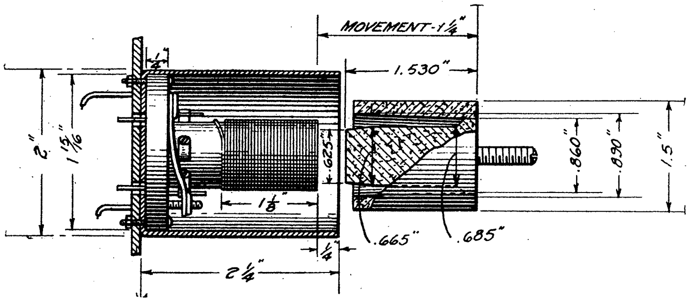


Fig. 5. Overall dimensions of tuning unit.

sible to obtain the powdered iron in any desired degree of fineness. Iron dust so fine that it will float in the air can be produced. The particle size which has been chosen for this use is 10 microns, approximately 0.00039 inch. The powder is, of course, of very high purity.

Before this powder is allowed to come into contact with air, the individual particles are insulated. This requires an entirely new insulator, especially developed for the purpose. None of the existing insulating materials was suited to the work. The film surrounding each particle is approximately one micron thick. This amount of insulation is adequate for the minute voltages generated in the particles by the magnetic field. Current is therefore effectively prevented from flowing between particles. The eddy current loss is therefore limited to the energy that can be dissipated within the particles, and this loss, in particles of the size mentioned, is low enough to permit successful use at the frequencies used in broadcasting.

This insulated iron powder is now molded with bakelite in much the same way that any other dry powdered filler, such as wood flour, would be molded. The molds are made of steel, as usual. Any desired form that is capable of molding in any material can be molded in this new iron, but the usual forms are circular in section, and the molds are therefore simple and inexpensive.

This new molded magnetic material is 92% iron by weight. But the remaining 8%, which is insulating material, so completely changes the electrical and magnetic behavior that it is really incorrect to still call it iron. At present we are referring to it as "Polydoroff iron" or as "Polyiron" which has the advantage of suggesting the minute subdivision of the iron. Eventually we shall have to have an entirely new name.

Permeability, in general, is the ratio between a magnetizing force and the flux which it produces in the material under consideration. But when alternating currents are involved, even at commercial frequencies, a more precise and complicated definition must be used. The presence of direct as well as alternating current still further complicates the matter. There is an extensive literature on this subject alone. As we approach the frequencies used in radio, all the usual definitions and methods of measurement cease to have any rational meaning. We are left, therefore, with no alternative except to state the permeability of the new material in terms of its effect upon the inductance of an air-core radio frequency coil into which it is inserted. On this basis, the permeability of Polyiron is about 8, which is adequate for the use we are describing, but I must caution that this figure is not to be compared with the direct current permeability of commercial sheet steels.

Hysteresis loss in magnetic materials at commercial frequencies, is proportional to the area of the hysteresis loop, and increases with frequency. But as we approach the frequencies used in radio, the area of the loop becomes disappearingly small, and the loss from this cause becomes negligible. Whatever effect the introduction of an iron core in a radio-frequency coil may have upon its effective resistance, is due, therefore, to the eddy-current loss. This loss may be reduced by shortening the paths which the induced currents can take, and by decreasing the resistance of these paths. This result is secured by lamination, which was carried to its practical limit in the one mil steel of the Alexanderson high frequency alternator. Beyond this, we may resort to powdered material, with the particles insulated, and this has been carried to the limit in Polyiron.

The extent to which the attempt to insulate the particles has been successful is indicated by the measured resistivity of the material. Here is perhaps the most unique property of Polyiron. It measures 50 ohms per centimeter cube, and, as you will see from the tabulation in Fig. 3, lies intermediate between insulators and conductors. No known material, whether ferric or not, lies within several orders of magnitude of this value. Polyiron has over five million times the resistivity of ordinary pure iron.

The losses in this new material are extremely low, but they increase with frequency. The core loss, in ergs per cycle, increases at a rate somewhat below the second power of the frequency, as shown in the upper curve of Fig. 4. The effective radio-frequency resistance of the core, however, increases almost as the fourth power of the frequency. How, then, can we make the high frequency resistance of the complete tuned circuit *decrease* with frequency, as it must if the performance is to remain constant? To answer this, I have only to remind you that the core is *withdrawn* to increase the frequency, so that as the frequency is increased, there is less and less of the iron present in the field.

The tuned circuit consists of a coil, wound on the usual bakelite form, a Polyiron core arranged so that it can slide into the coil, and a fixed condenser, usually of mica, with an adjustable blade, to secure initial resonance, with the core all the way out, at 1,500 kc. The condenser is mounted on a suitable ceramic base, and the coil and condenser on its base are mounted inside a cylindrical shield of aluminum or copper. The condenser is connected across the coil. There is no electrical connection to the core, but it is usually insulated from the grounded frame of the net, to prevent capacity effects. As shown in Fig. 5, the overall dimensions of the complete tuned circuit, with the core all the way out, are only 2 inches diameter by 3¾ inches long, a total volume of less than 12 cubic inches.

Note that there will be no leads to variable condensers at some distance. Also note that there is no primary on this coil, that it is not a transformer. There are only three leads from such a tuned circuit, one to a grid or plate, one to a B or C voltage supply, and one ground or to a coupling condenser. The circuit is therefore simple, and the shielding simple and inexpensive. The circuits may be placed as close together as desired, so long as the cans do not touch.

The internal member of the core is an easy fit inside the coil form. The inside diameter of the outside member of the core is made sufficiently large so that there is no possibility of its touching the winding. The total movement of the core is 1¼ inches. The winding is preferably of Litzendraht. In the usual condenser-tuned circuit this wire

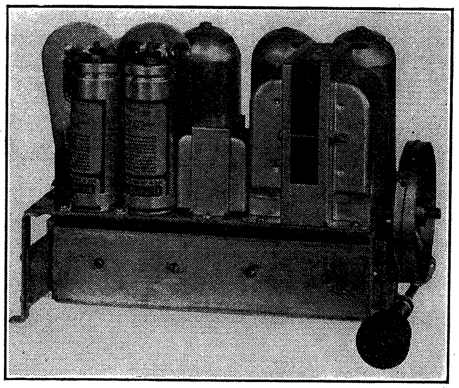


Fig. 6. First model of permeability tuned receiver.

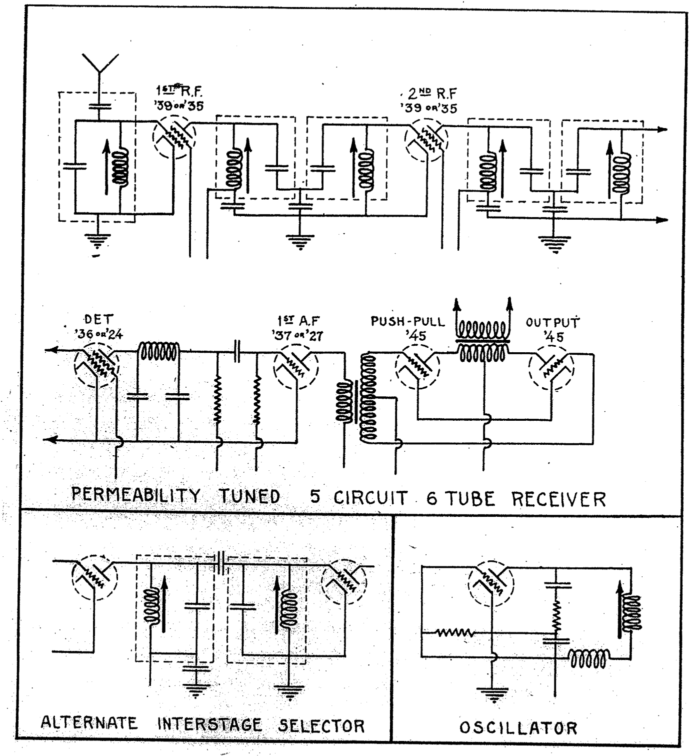


Fig. 7. Condenser coupling of plate and grid circuits.

does not have sufficient advantage to justify its use, but in the very much smaller inductances used in the permeability-tuned system, the stranded conductor gives a worthwhile decrease in the resistance at 1,500 kc., the frequency for which the coil is designed. The preferred wire has 10 strands of No. 41, which is a size standard with the wire manufacturers.

In Fig. 6 is shown the first permeability-tuned receiver employing the new core material. It had three radio stages, and four tuned circuits, with detector, output tube and rectifier, six tubes in all. The tuned circuits were assembled as a unit, and mounted under the chassis pan in such a way that the coil terminals came directly under the socket terminals making the leads extremely short. You will notice, at the bottom, the bridle which carries the four cores and the screws by which the positions of the cores were adjusted. This bridle slid back and forth on guide plates, one at either side, and was driven by a linkage at each end of a shaft running across the back of the unit. The sensitivity of this receiver was better than 1 microvolt, and it would successfully reject a signal 10 times as strong as the desired signal on the adjacent channels.

Practical Application

The development since this first receiver was produced has been chiefly in two directions: first, to produce a more effective and less expensive mechanism and, second, to determine the form of circuit best adapted to take full advantage of the unique properties of the new system and the high amplifying capabilities of the later screen grid tubes. As a result of this work, the latest chasses are quite different, both mechanically and electrically, and they are correspondingly better in performance, lower in cost, and more completely adapted to quantity production in a modern factory. Because of the inherent savings of space which result from the method, no attempt has been made to crowd the new designs into the smallest possible compass. There is, therefore, ample room for easy wiring and assembly, and yet the complete chassis is smaller and lighter than any of the current condenser tuned chasses of equivalent performance.

The circuit development has led to the adoption of a condenser coupled arrangement with both plate and grid circuits tuned, as is shown in Fig. 7. The antenna circuit, which directly feeds the grid of the first tube is also tuned so that we have five tuned circuits, but only two radio-frequency amplifier tubes. The antenna circuit is made to follow the other tuned circuits exactly by initial adjustment of the series antenna condenser and gives a gain on the first grid of from 18 to 22. The value of this preliminary tuning, before any amplification takes place, reducing the value of interfering signals and inductive disturbances before they reach the first grid cannot be over-estimated. That this produces a marked improvement in performance is apparent the moment the receiver is tuned to the first signal.

In all the tuned circuits the inductance value, measured without the core, is 65 microhenrys, and the capacitance is 160 mmfd., which is approximately three times the minimum capacitance, effective at 1,500 kc., in condenser tuned systems. The coupling condensers are .02 mfd. Other constants of the radio amplifier and the complete audio amplifier are normal.

The symbol used here to indicate variable permeability has simplicity if nothing else to recommend it, and it has been found to be not easily confused with other features usual in radio diagrams.

At the lower left is shown an alternate arrangement for the tuned circuits between the tubes which more nearly corresponds to the forms that have been used with condenser tuning, but, perhaps for that very reason, is not quite so constant in performance over the range. There is also shown, at the bottom right, the circuit for an oscillator, which will have very nearly constant output.

The five tuned circuits are assembled into a mechanical unit illustrated in Fig. 8 actually smaller than the usual

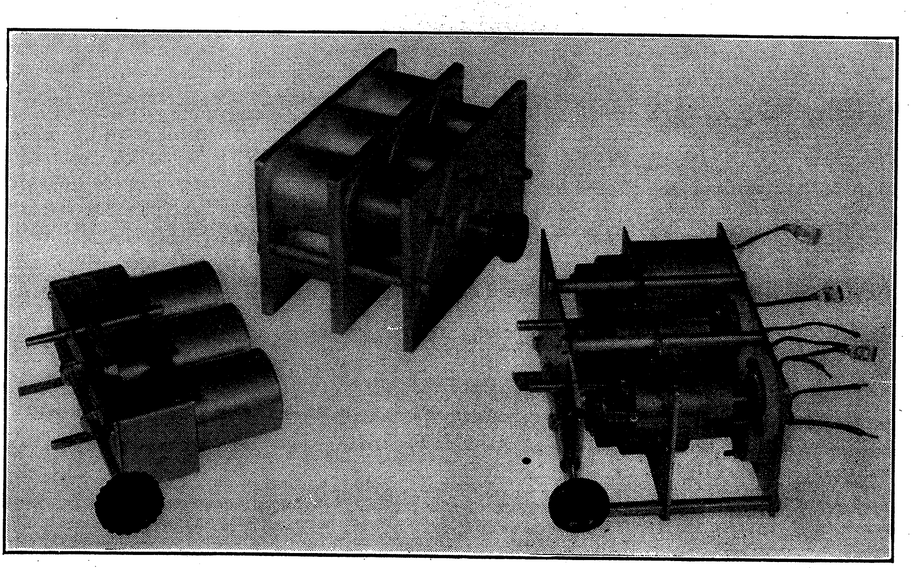


Fig. 8. Assembly of tuning units.

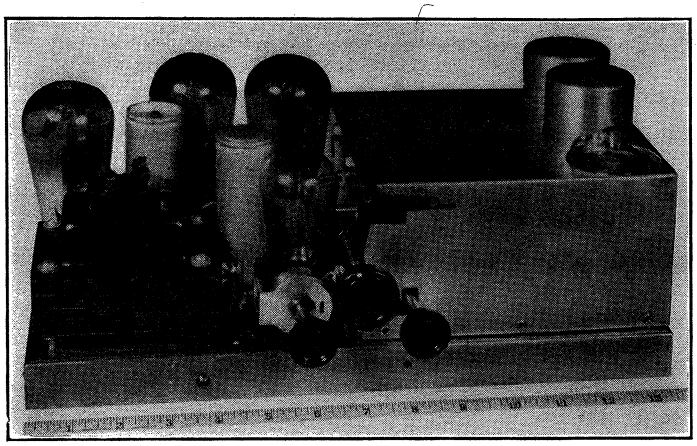


Fig. 9. Completed chassis.

five-gang condenser. The cores are mounted on a rigid bridle, actuated by a short rack and a cooperating pinion on the knob shaft. Any reasonable motion reduction can thus be easily secured, and this without complicating the very simple indicator, which can be adapted to either "full-vision" or the more usual type of dial, and is automatically "straight-line-frequency."

In the view at the lower right, some of the shield cans have been removed to show the coils and cores, and the insulating bases that support the mica condensers. The three top wires, with clips, connect to the grids of the two radio tubes and the detector, the black wire to the antenna terminal, and the four remaining wires to the two plates, and to the B supply. The coils are mounted directly on the back plate, not on the porcelain, in such a way that they may be adjusted to give the initial correct position with respect to the cores which are rigidly mounted on the bridle.

Since both the inductance and the capacitance are capable of adjustment, the inductance by the relative position of the core and coil, and the capacitance by the small adjustable leaf on the fixed condenser, the receiver is aligned after it has been completely assembled. There is no step equivalent to the necessity, in condenser-tuned systems, of aligning the gang unit before it is assembled on the set. The only source of variation is the moulded cores, and these are made in the same mould, under the same temperature and pressure, from a weighed quantity of material from a large and thoroughly mixed batch. Careful checks have shown that the degree of reproducibility is very high, and that the maximum error in a five gang unit will be less than one-half of one per cent. There is the further advantage that the maximum error occurs at 550 kc. where the stations have the greatest per cent separation. The method of alignment produces exact agreement at two points in the range. With the cores all the way out, the circuits are definitely tuned to a 1500 kc. signal, by adjustment of the condensers. The cores are then advanced to a mid position, and exact resonance to a 1000 kc. signal is secured by adjustment of the position of the coils with respect to the cores.

The overall alignment is thus actually better than can be secured by the prior calibration of variable condensers and coils in the usual system, and nothing short of actual tinkering will change it after it has once been established. The effect of changes in temperature is nil, and there are no parts sufficiently delicate to be displaced due to jars received in shipment. Slight differences between the inductance values of the coils are of no consequence, provided the coils are geometrically alike, and this is secured by using moulded forms.

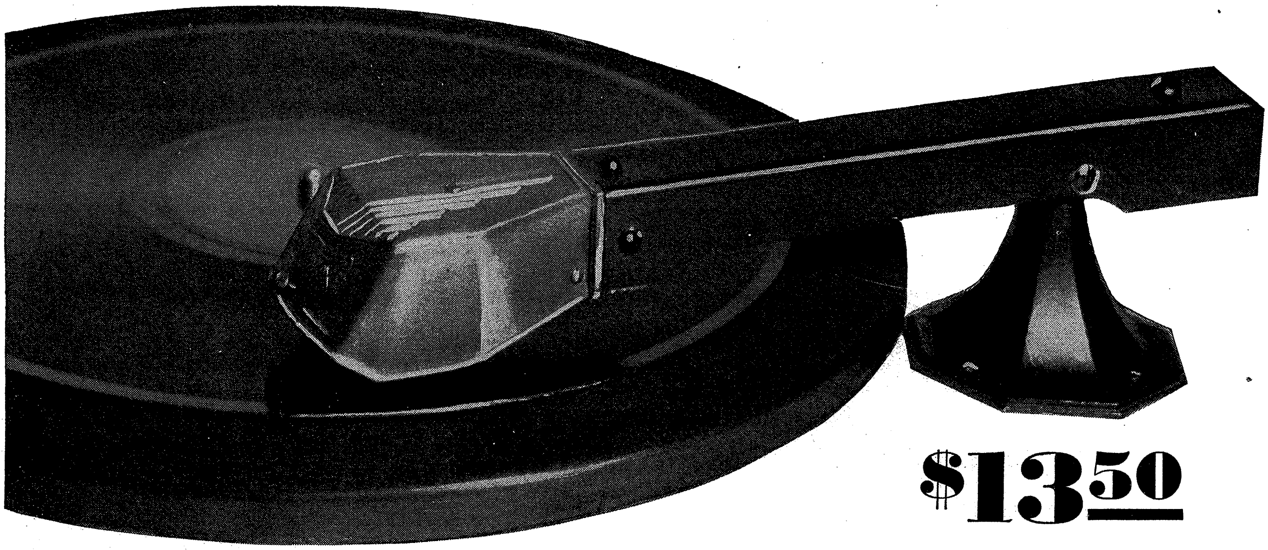
Another form of unit, shown at the center, Fig. 8, is directly adjusted by a screw passing through the bridle. This type may be more adaptable in some applications. There is also shown, at the left, a three core unit intended for possible use as a pretuner in superheterodynes.

In the completed chassis shown in Fig. 9, the units have been so arranged as to bring the three controls out at the center, so that adaptation to any cabinet design would be easy. Other arrangements, to suit particular cabinet designs can of course be made. Because there is no variable condenser gang, and because each tuned circuit is complete in itself, the wiring under the chassis pan is very much simplified. The receiver shown is only an "engineering model" and still requires the attention of the factory or production engineers to eliminate those little difficulties of assembly and wiring which make such a large difference in the speed of production and in the cost. Being almost completely hand made, it does not present the finished appearance of a factory product.

It is a matter of some difficulty to give anything amounting to an accurate cost comparison. The cores themselves will cost no more than the variable condensers which they replace. Beyond this there are a number of direct and indirect savings. The coils, for example, have a very much smaller secondary winding, and no primary. Nor have they any compensating windings. They are smaller in diameter, and so are the shield cans. Thus the space now occupied by the variable condenser gang is completely saved, and the space required for the coils greatly reduced. The high frequency wiring is materially simplified and shortened. Since the tuning and coupling condensers are mounted inside the shield cans, which are magnetically closed by the cores, the shielding is also greatly simplified. Compared to the superheterodynes, the oscillator and its tuned circuit and coupling means are saved. Even if the cores had to be sold at a slight advance over the cost of the variable condenser sections, there would still be a considerable saving.

One factor deserves to be emphasized. Receivers built in accordance with the new method will be strikingly new and different, both in appearance and in performance. The dealer first, and the public later, will be conscious of this difference. And they will conclude that a worthwhile new contribution has been made to the art of radio reception. This is the factor which more than any other recommends permeability tuning to the sales managers and the executive heads of the industry.

To the inventor, Mr. Polydoroff, and to Mr. Victor S. Johnson, who supported him, goes the credit for having successfully completed an important and courageous research addressed to the problem of radio reception.



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Amy, Aceves & King, Inc.

Consulting Engineers

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Some of our Recent Developments

Multicoupler Antenna System: This system comprises a well designed antenna with one or more downleads to which as many as thirty radio receivers may be connected by means of specially designed coupling devices, known as multicouplers. The reception of each radio set is excellent, whether one or thirty sets are connected to the common antenna. It may readily be installed either in a finished building or one in course of construction.

Electronic Multimeters: After a year's development and research in our laboratory, we have perfected for the Rawson Electrical Instrument Company, several types of electronic milli-voltmeters and micro-ammeters of unusual design in a manner never before attempted.

Tone Compensating Circuits for the Improvement of Audio-Amplifiers: Special circuit arrangements were developed for adapting tone control to radio receivers or electrical phonograph pickups. Deficiencies in phonograph records or loud speakers can be overcome by means of these special circuits.

Radiotherm Machine for Hospital Use: Apparatus of unique design was developed for the French Hospital, New York City, for the application of radio frequency oscillations to produce fever in the human body.

Photoelectric Amplifiers: A portable unit for measuring ultra-violet light was developed, as well as many ultra-sensitive circuit arrangements for visible light cells.

Triple Twin Circuit Improvements: After many months of special research and development work for the Revelation Patents Holding Company, a number of basic and important circuit arrangements were developed for the commercial application of this tube.