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NEW METHODS OF RADIO PRODUCTION†

by
J. A. Sargrove (Member)*

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SUMMARY

The paper deals with a new conception of designing electrical apparatus such as that employed in communication, embracing telegraphy, telephony, television and light-current electrical applications generally and provides an improved and more economical method of circuit manufacture.

In order to give electronic apparatus, a form which lends itself to fully mechanized production methods, a principle has been evolved of treating a circuit, not as an assembly of component elements but as a "compound" whole. Deposited conducting materials and a preformed dielectric plate replace the chassis and the multitude of parts in their more familiar form.

Unlike earlier methods, in which connecting paths between prefabricated components were formed by deposition, in the method described the plate is given a predetermined structural form which determines the electrical characteristics of the completed circuit. The insulated plate, apart from acting as the support, also serves as the coil former and the dielectric of fixed capacitors.

The design conception is such that electronic circuits can be produced in final form by a fully automatic electronically controlled processing machine which is described as "E.C.M.E."—the Electronic Circuit-Making Equipment. (Section 5.)

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INTRODUCTION

It is not within the scope of the paper to deal with economics of radio production, but a slight excursion into this realm is necessary to explain the motive which has led to this development.

By reason of the many complexities and numerous components involved in a radio receiver, such apparatus does not, in its existing form, lend itself to a high degree of mechanization.

Hitherto, it has not been possible to introduce automatic machinery to deal with assembly or testing, or to decide which piece of apparatus is good or bad. Of necessity, these operations have been carried out by hand.

The normal method of manufacturing a radio receiver is to mount the individually-made components on a supporting base or chassis, and often with some components arranged on separate sub-panels, and then connect them up in the desired

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relationship by means of conductor wires soldered to the terminals of the various components. All the individual component parts have to be separately fabricated or purchased and tested before construction commences. Then the set is assembled and wired by hand, being subjected to numerous tests during the journey along the production line.

Since the human element figures so largely, the result is a comparatively costly instrument in which rejects must be reclaimed at additional expense to the entire production because completed units are too valuable to scrap.

Many suggestions have been made in the past for facilitating the manufacture of radio receivers ✕. It has been suggested, for instance, that conducting paths on a plate of insulating material, sheet bakelite or ceramic could be formed by means of:

(*a*) Spraying metal through stencils. (2, 8, 11)

(*b*) Electro deposition on to a network of graphite lines printed on the surface of the plate. (1)

(*c*) Printing on the surface of ceramic plates organic silver compounds which are then decomposed into silver by firing in pottery kilns at temperatures above 1,000° C. (25)

To deposit graphite between appropriate points in the network to form resistors. Coupling capacitors made in the form of thin flat elements mounted by hand and soldered against the surface of the plate. The circuit is then completed by the addition of the remaining components, such as coils, which have to be separately made and soldered in. (8)

(*d*) It has been suggested that a conductor system could be produced for electrical apparatus by die-casting prefabricated components. Thus, by arranging them in the die with their solder tags so positioned that after the die-casting has been effected the casting as a whole can be removed from the mould, and will comprise the conductor system and whatever elements have been cast into it. (16, 17)

Further, it was suggested that in this die-casting method a supporting plate of laminated bakelite might also be inserted into the mould so that, after casting and the cast conductor system allowed to cool down and harden sufficiently, it could be removed from the mould together with the supporting plate. (16, 17)

✕ *See Prior Art and Bibliography, p.*33.

So far as it has been possible to ascertain, none of these proposals have ever been carried out in practice for domestic radio production, and only the so-called silver printed wiring has been employed for a special war application in the manufacture of "proximity fuses" for projectiles.

In none of these earlier suggestions and methods has the prefabrication of coils and capacitors been eliminated or hand assembly avoided. Although some of these proposals have several merits, they do not effectively reduce the cost of radio set production. This point is emphasized by the reluctance of manufacturers to seriously consider adopting these systems.

New Method

The new method, now to be described, is at present being successfully carried out and differs from these earlier methods in many respects.

The most notable difference is that the insulating plate employed is not merely a supporting device. It is moulded into such a structural form that, when fully processed without manual aid, it contains the inductors, capacitors, resistors, potentiometer tracks, switch and other terminations together with conductor paths in an interrelated and interconnected manner.

The above component elements are not prefabricated but come into being *in situ*. They are "grown" together with the conductor paths. The insulating material of the plate forms the dielectric of the capacitors and is therefore an integral part of the circuit, predetermining the characteristics of the other elements.

Section 1

NEW CONSTRUCTION METHODS

In order to give electronic apparatus, such as a radio receiver or television equipment, a form which lends itself to fully mechanized production methods, a principle has been evolved of treating a circuit, not as an assembly of component parts, but as a compound whole, by depositing metal into preformed moulded plates which replace the conventional metal chassis of orthodox receiver construction practice.

The plates, themselves, are of special designs, incorporating grooves and depressions on both sides. In some cases such indentations are directly physically opposed to form in between a very fine web of insulating material.

These grooves and depressions are so arranged as to constitute, after metallization, the conductors, inductors, capacitors, fixed members of variable capacitors, resistors, potentiometer tracks and interconnections all in continuous relation one with another, as seen by reference to Figs. 1 and 2 (p. 4).

In this manner complete circuits are simultaneously produced without costly or tedious assembling and the wiring of separate components. At the same time, hand operations are eliminated by processes to be described later.

It will be appreciated, of course, that components such as valves, loudspeakers and electrolytic capacitors cannot be applied in this manner, but the extent and scope of this form of construction will be apparent when practical applications of these principles to the construction of a radio receiver are fully described (section 2—3).

The term "plate," it should be noted, is not limited to flat constructions, as these principles

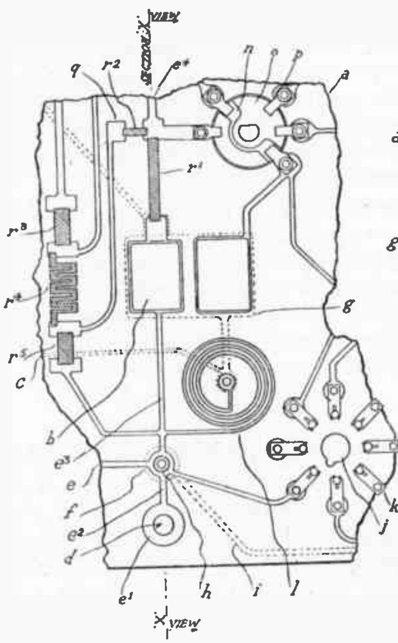


Fig. 1.—*Plan view of part of a plate showing interrelated components and circuit elements or connections.*

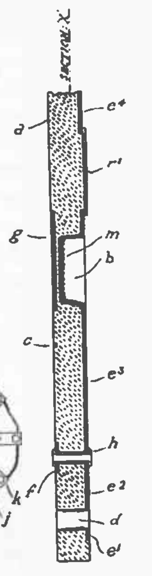


Fig. 2.—*Shows a cross section on the line x-x of Fig.* 1.

can be applied to curved surfaces and, in particular, to the walls of cabinets containing parts of the apparatus.

Moreover, the term "insulating" is not to be taken as implying that the plate is wholly of insulating material, as in some cases, conductive material may be inserted in the body of the plate.

In order that this method of design may be understood more readily, and to introduce the forms given to various component elements, reference is made to accompanying drawings.

1.1. Compound Treatment of Circuits

Referring first to Figs. 1 and 2, the plate *a* is of insulating material and has upon both side surfaces indentations of different depths such as *b* which, when partly filled with metal (shown black and indicated by the reference *m* in Fig. 2), form one pole, or plate of a capacitor. The plate also contains grooves, (*c*) filled with metal forming a conducting path or connection which under orthodox methods of manufacture would be a wire soldered at both ends. The hole (*d*) for fixing this panel mechanically to some other part of the apparatus, e.g. the cabinet, is surrounded by a circular groove filled with metal e^1 which is interrelated with grooves similarly filled with metal such as *e*, e^2 and e^3.

A typical interconnection from conductor paths *e*, e^1, e^2 and e^3 on one side of the plate *a* to conductor paths on the other side such as *f*, is shown between metal deposit e^2, with metal deposit *f* located on the other side of the plate, the interconnection being provided by an eyelet *h* pressed and riveted into a suitable hole.

Other conductor paths on the other side of the plate are groove *i* connecting point *f* and some other element not shown, and the shallow indentation *g* which lies directly opposite the deeper indentation *b*.

The latter two metallised indentations (*g* and *b*) form a fixed capacitor the dielectric of which is of the same moulded plastic substance as *a* and is preformed at the same time as the whole plate, a thin web *w* (Fig. 2) being produced in the mould.

The preceding shows a typical case of a fixed capacitor formed *in-situ* all ready for use, completely interconnected to the circuit network and requiring no prefabrication or manual assembly, wiring or soldering operations to connect it into the circuit.

At *j* a hole with a keyway is shown. This serves to locate a thermionic valve into the surrounding valve pin contact sockets such as *k*. It will be seen that these valve pin contacts are eyeleted into enlarged termination lobes at the ends of the deposited metal conducting paths. This is an operation easily mechanized and avoids the consequent need for wiring up a separate valve holder.

Coil *l* is a high frequency choke, the outside turn of which is directly interrelated with the conducting path e^2, e^3. The inside end communicates by way of an eyelet connection with an enlarged lobe of conducting path *c* and *g*, in the other side of the plate *a*.

In a similar form to the interrelated deposited metal configurations on the main body of plate *a*, associated metal deposits can be arranged on a movable circular panel inserted into a clearance hole such as the switch rotor disc *o*. In this case the deposit *n* forms a movable metallic link between the switch contacts such as *p*, which can be arranged around *o* at any convenient position.

It will be seen that the stationary switch contacts *p* are eyeleted into the enlarged termination lobes of the deposited metal conducting paths. This is another operation easily mechanized and avoids the laborious switch wiring operation, and also circumvents the need for careful inspection, after wiring, which is normally required to avoid wrong connections.

To ensure better contact for the switch the link deposit *n* can be reproduced on both sides of the rotor disc *o* and the stator contacts, such as *p*, can also be duplicated on both sides.

1.2. Deposited Resistors

Having shown, by way of example, a wide range of circuit components and conducting paths that can conveniently be deposited of one kind of conducting material (e.g. copper), other circuit elements, e.g. resistors, can be produced *in situ* such as r^1 (Figs. 1 and 2) by depositing graphite on to the surface of plate *a* in the space between the metal deposits e^4 and the enlarged lobe of deposited metal plate *b* of a capacitor, thereby connecting it into the circuit simultaneously with the formation of the resistor.

This avoids the need for manually inserting a separately prefabricated resistor component.

The deposited resistor elements, such as r^1, r^2, r^3, and r^4, etc., can all be simultaneously deposited by employing printing technique, or by using masks or stencils and spraying this suspension of graphite with the aid of a paint-spraying pistol.

Provided the specific density and thickness of the graphite deposit or other resistive material is accurately controlled, the various resistor values required can be obtained by merely varying the aspect shape of the resistor deposit. As an example, a certain colloidal dispersion of graphite in a slightly glutinous medium (such as gelatine) and deposited to a controlled thickness of, say $\frac{1}{20}$ millimetre we obtain a specific coating resistivity of 25 ohms per square millimetre area when measured from one edge to the parallel edge opposite. This small area is capable of continuously dissipating one milliwatt of energy in the form of heat without rising above a safe working temperature. A wide range of resistor values can be obtained by simply varying the shape and size of the deposit. A few examples will serve to illustrate this. A deposit area 1 mm. wide and 100 mm. long will give, in the above case, a resistor of 2,500 ohms. This will be able safely to dissipate $\frac{1}{10}$ of a watt (100 milliwatts). Again, a deposit of 10 mm. wide and 10 mm. long will have a value of 25 ohms and dissipate $\frac{1}{10}$ watt; another deposit 0·2 mm. wide and 100 mm. long would have a value of 12,500 ohms at $\frac{1}{50}$ watt; whereas a deposit 25 mm. wide and 40 mm. long would be 40 ohms at 1 watt.

Other ranges can be obtained with similar shapes by varying the controlled thickness of deposit, simply by altering the spraying time, or by changing the density of the deposit achieved by varying the dispersion of graphite in the medium.

In large scale production several pistols can be used for depositing various dispersions of graphite in sequence, in each case a different stencil arrangement being employed so that the required deposit is appropriately placed in the circuit.

In practice, one can easily obtain a range of values from 1 ohm to 10 megohms with three different dispersions. Wattages in the lower ohmic values can be up to 10 to 20 watts. This range of values is ample for radio receiver practice. It may be considered a disadvantage of this method that the higher wattage values of resistor occupy more surface space than is the case with the prefabricated solid stick-like resistors. This is not necessarily a disadvantage as the heating up and continuous heat dissipation of these resistors is much more uniform, and the reliability, constancy and endurance of resistors made by this method is very high.

It should be noted that the larger wattage resistors can be conveniently sprayed on to the surfaces of the cabinet walls, on which the heat radiating elements can be well spaced.

It should be noted, too, that the contacts to the two ends of the resistors are obtained without a separate operation by depositing a resistor into its correct place in the circuit so that it overlaps the previously (or subsequently) deposited metal conductor path deposit over a sufficient area to achieve good contact. It is preferable so to shape the larger wattage resistors that the graphite deposit is widened near the contacts. This ensures that the temperature gradient, at the line of contact between hot graphite and cold metal, is not too sudden.

To enable a very long and narrow resistor to occupy a relatively small surface area it can be conveniently deposited in zig-zag form. Such a resistor is shown at r^4 (Fig. 1).

It is further convenient, in order to allow for slight inaccuracies in the alignment of the stencils, to make the terminations of the metal paths also with enlarged lobes. Such a termination is shown at *q*.

1.3. Deposited Inductors

Whereas the inductor coil shown in Fig. 1 has only three turns, and thus has only a very small inductance value, coils of this construction can be made with many more turns of narrower surface width and closer spacing, and also with a total greater surface space area.

Obviously, the maximum value of inductance that can thus be obtained has a top limit which is lower than that of the conventional wire coil. Several methods of raising the maximum inductance value of coils made in accordance with the present proposals are shown in Figs. 23 to 38 and will be more fully described hereafter. In general, the kinds of inductor required for radio frequency work of the order of approximately ½ Mc to 100 Mc/s can be arrived at by the simpler means shown. There is a way of increasing greatly the inductance values obtainable, and that is to affix to the panel a strip of photographically developed deposit representing a portion of the circuit, mainly the inductance. Thus, by photographic means the grain size of the metal is greatly reduced, and hence a larger number of turns can be compressed into a given panel area.

1.4. Deposited Capacitors

There are certain limits to the values of capacitors that can be formed in the manner shown in Figs. 1 and 2, and if larger capacitance values are required these can be obtained as follows. The capacitor can be produced *in-situ* by depositing, first, two metallic contacts one of which is as large as a capacitor plate. This is sprayed with a lacquer of high dielectric coefficient and over a narrow edge of the larger plate, both of which are masked. A further mask is now used, having a large cut-out and enabling metal to be sprayed through it so that it makes contact with the metal conductor of narrow dimensions. This forms the second plate of the capacitor. Again, lacquer is sprayed on through the stencil previously used for lacquer. Then metal is again applied through the first metal spraying stencil; and so on until a stack is produced in which every alternative metal layer forms one pole of the capacitor and vice versa. Of course, three or more pole capacitors can be similarly produced. Moreover, many capacitors in many parts of the circuit can be similarly and simultaneously made in this multiplate form. Other interrelated parts or conductor paths can also be sprayed on top of the lacquer, allowing, for instance, a conductor path in between lacquer layers to cross over other conducting paths on the main panel as in between other lacquer layers.

An alternative method of producing such interrelated capacitors of higher value is to make the whole main plate from a material of very high dielectric coefficient. For example, by using a plastic filler with a high dielectric constant, or by inserting a thin layer of such a substance (with a roughened or etched surface) into the mould so as to form the thin web *u* (Fig. 2) when the plastic moulding is completed.

A further alternative is to make a sub-plate of a substance having a high dielectric constant, on which part of the interrelated conductor paths and the high value capacitors are deposited. This sub-plate is connected into the main circuit by eyelets which also provide the electrical connections between the circuits on the two plates. In general terms the upper limit of capacitance values that can be conveniently produced by these means lies in the region of 30 pico-farads per sq. cm., using the material known under the trade mark "Bakelite" as the plate material, and up to 0·03 microfarad with special materials such as a suitable ceramic.

In practice, it has been possible to obtain all the additional capacity required by the simple expedient of introducing corrugations in the web forming the capacitor dielectric. By increasing the effective area in this way the upper limit of the capacitance value is substantially raised where required, without occupying more space on the surface of the plate or separate dielectric to 100 pF/cm^2.

To obtain the greatest production economy the circuit designer should preferably avoid the larger values of inductance and capacitance. (In many cases the required time constants of a part of a circuit can be obtained with smaller values of reactive components if the corresponding resistive component is increased.)

When larger reactive components are indispensable (such as electrolytic capacitors) these can be prefabricated with plug-shaped outlets and plugged into suitable sockets inserted into enlarged lobes of the interrelated deposited metal circuit on the main plate *a*.

Section 2

PRINCIPLES APPLIED TO DESIGN

Having explained the general principles, reference is now made to Figs. 3-22 which illustrate the method of production of a complete A.C./D.C. all-mains, two-valve radio receiver. The complete circuit is shown in Fig. 22 (p. 16).

Figure 3 is an isometric, perspective view of one side of a moulded plastic panel 1 of insulating material prior to deposition of any other materials. The arrow which appears on the narrow edge of the panel on this and several subsequent figures serves to show which side of the plate is viewed and should be imagined as permanently inscribed on the plate.

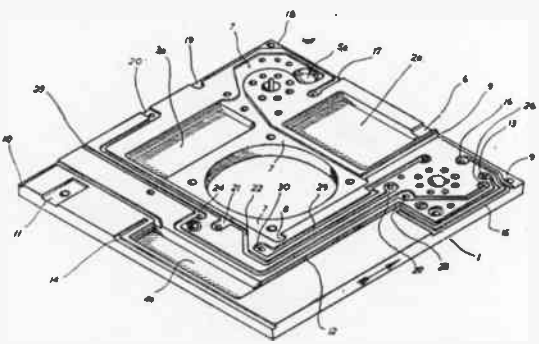


Fig. 3.—Perspective view of one side of a plate moulded from insulating material upon which a two-valve amplifier for a radio receiver is to be built up.

Figure 4 shows the same side (see arrow) of the plate at a later stage in the production process after the moulding has been metallized all over by any known means (e.g. metal sprayed from a pistol or by electro-deposition), and the whole machined down by a face-miller so that only metal deposited in the grooves, holes and indentations remains on the plate.

Figure 5 (p. 8) shows the circuit scheme which this panel will ultimately carry. It will be noted that this is the same electrically as the portion between the vertical dot-dash lines of the completed receiver in Fig. 22. However, an unconventional mode of showing the circuit has been adopted in Figs. 5, 8, and 14 to show the progress of production sequence. In these three figures, which all

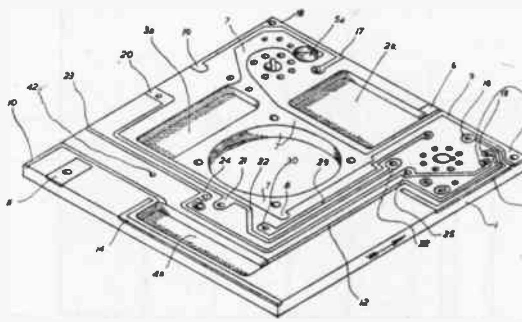


Fig. 4.—Shows the same side of a plate shown in Fig. 3, after the grooves and depressions have been filled with conducting material.

represent the same circuit, all those parts not yet present on the plate shown in the preceding figure are shown with very thin dotted lines. These circuit components and conductor paths on top, i.e. visible, in Figs. 3, 4, and 6 are shown with full black lines, whilst those on the nether side in these figures, but on top in Fig. 7, are shown as thin double contour lines.

The arrows in Fig. 6 and Fig. 7 serve to indicate which way up the plate is shown on the various figures.

Deep indentations 2a, 3a, 4a and 5a in the moulded panel 1 in Figs. 3 and 4 are intended, after metallization, to form the top plates of each of the capacitors shown with the same number in the circuit diagram (Fig. 5). To distinguish these deep indentations from "through" holes, the shadow cast by the walls of the indentation is shown on the webs of moulded plastic material at the bottoms of the indentations. These thin webs will form the dielectric of the capacitors. The reference characters 6 to 30 in Fig. 3 are shallower indentations and grooves which will later serve as inter-connecting conducting paths and termination lobes of sockets or eyelets. Their exact function is clarified by comparison of Figs. 3 and 4 with Fig 5. The number 7 which occurs several times in Figs. 3, 4, 6, and 7 relates to a large irregularly-shaped, interconnecting metal deposit, and its purpose is to act similarly to an earthing bus-bar of the metal chassis of a conventional receiver. It can be conveniently applied so that it is in continuous and intimate contact through the large round hole in the middle of the panel with another large inter-

Figures 6 and 7 show the application of the resistor elements, the resistors being shown as shaded areas. One operation only is required for each side, the two sides being sprayed with a different graphite dispersion, the specific resistance of the graphite deposit on the side of the plates shown in Fig. 7 being approximately ten times higher than that shown in Fig. 6.

Viewing Fig. 8 and, where necessary, the preceding figures, it will be seen that we have resistor 31 (Fig. 6) of graphite deposited in a meander or

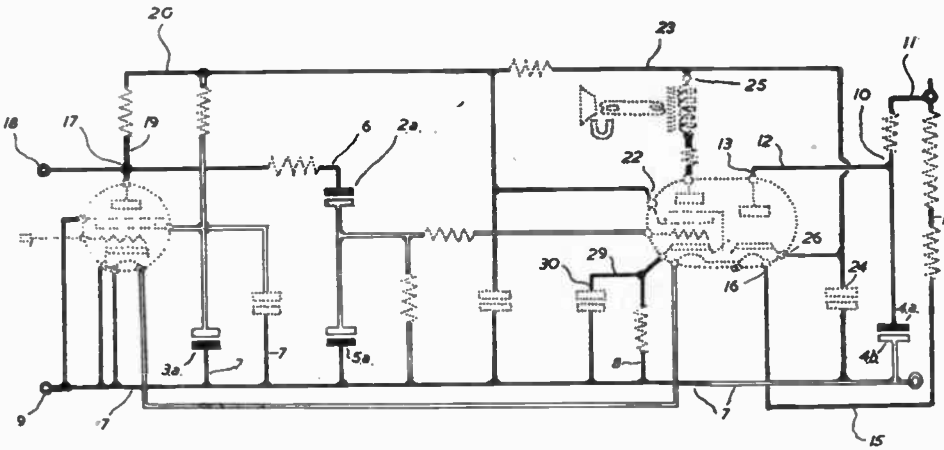


Fig. 5.—Circuit diagram of complete amplifier. Dotted lines represent parts not yet in existence at this stage.

connecting metal deposit on the other side of the plate. This is also marked 7 in Fig. 7 (p. 9).

In most radio receiver designs it is good practice to make this element as all-embracing as possible, and to be continuous with the earthed capacitor plates as shown at 3a and 5a in Fig. 4, and at 4b in Figs. 5, 7 and 8.

The various groups of smaller holes will be described later. The full black, and the double thin lines in Fig. 5 show how many separate assembly operations, fixing, wiring and soldering, of the normal set-making procedure have been eliminated by the simple and economical expedient of designing the plate moulding with suitable grooves and recesses. Also by metallizing this plate all over and removing the surplus metal from both sides so as to leave the metal only in the grooved or recessed places.

Before explaining the parts in detail it will be noted that one of the reasons for the use of both sides of the plate is to allow the conductor paths to cross over each other, where required, by the circuit.

Another reason is to facilitate the arrangement of the fixed capacitors in the circuit.

zig-zag form between the lobes of metal conductors 19 and 20 to act as the anode load for the first valve. Another meander form resistor 32 is inserted between conductors 20 and 23 to act as a smoothing filter resistor. A straight, narrow resistor with

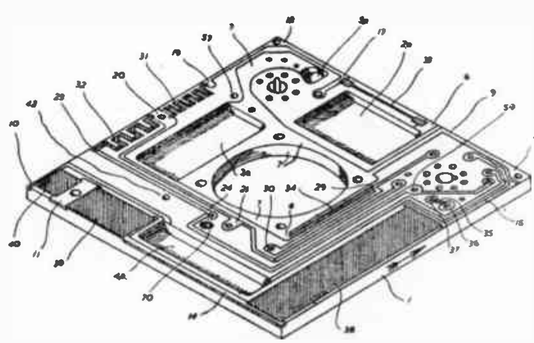


Fig. 6.—Resistors have now been added to plate shown in Fig. 4.

enlarged ends 33 is deposited between conductors 6 and 17 to act as a high-frequency stopper to assist regeneration in the aerial circuit which will be connected to point 18 (see Fig. 22).

A straight resistor 34 is deposited between conductor lobes 8 and 29 to act as a cathode-grid biasing resistor for the second valve of the set.

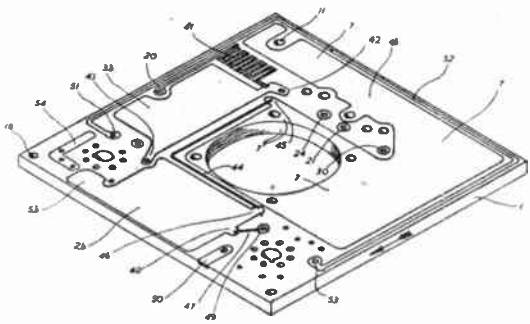


Fig. 7.—The reverse side of plate shown in Fig. 6 at this stage of production.

A very small resistor 35 is deposited between the circular metal deposit 36, which will ultimately be the contact for holding one of the loudspeaker sockets 56 (see Figs. 9 and 10) and a similar circular metal deposit 37 which will ultimately be the contact holding the appropriate one of the valve socket eyelets (such as 55, Fig. 9). This resistor will act as an anti-parasitic oscillation anode stopper for the second valve. The very large resistor 38 is deposited between metal conductors 14 and 15, and acts as part of a heater-filament series resistor. This is a good example of a relatively large wattage resistor. Another large resistor 39 is deposited between metal conductors 11 and 14 and acts as other part of the heater-filament series resistor.

It should be noted that the arrangement of splitting an electrical circuit component—in this case the heater-filament resistor—into several parts, either for the purpose of better utilization of the available plate space or for any other purpose, (e.g. spreading the heat radiating members to different regions of the panel or the cabinet) is easily accomplished and furthermore, this does not involve an increase in production costs.

The resistor 40 deposited between metal conductors 10 and 11 serves to limit the charging surge-current flowing out of the rectifier valve when the receiver is first switched on. For this purpose it has a comparatively large area and will stand very great overloads. Conductor 10 also communicates with the metal deposited capacitor plate 4a (Figs. 4, 5 and 6), which acts as a by-pass to earthing metal deposit 7 for parasitic high frequency oscillations generalized by the rectifier valve.

The meander form resistor 41 in Fig. 7 on the under side of the plate (and consequently shown as double thin lines in Fig. 8), is deposited between the lobe 42 of this capacitor plate 3b and conductor path 20 which transcommunicates by way of a small hole with conductor path 20 on the under side (Fig. 6). This acts as a feed resistor for the screen grid of the first valve via the lobe 43 of the capacitor formed by deposited plates 3a (Fig. 6) and 3b (Fig. 7), the latter acting as a high-frequency by-pass capacitor for the same electrode. A very thin and long resistor 44 is deposited between the lobe 45 of the main earthing conductor deposit 7 and lobe 46 of the nether

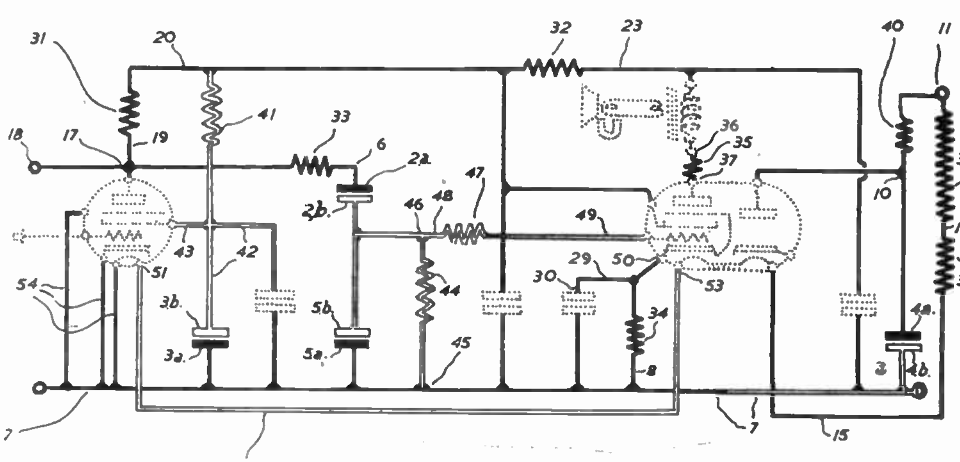


Fig. 8.—The same circuit shown in Fig. 5, with parts now completed represented by full lines.

plate 2b of the audio-frequency coupling capacitor composed of metal deposits 2a (Fig. 6) and 2b (Fig. 7). It will be noted that in the circuit shown in Fig. 8, the capacitor plate 2b is in intimate, direct contact with capacitor plate 5b, the latter serving to produce a high-frequency by-pass for the control grid of the second valve. This direct contact is achieved as shown in Fig. 7 by making 2b and 5b into one individual peculiarly shaped metal deposit as their opposed two separate deposits 2a and 5a are in juxtaposition on the other side of the plate shown in Fig. 6.

This facility of making high-frequency by-pass capacitors in such intimate contact with the main (base) earth return is an advantageous feature which is not normally accomplished with such production economy. The very thin resistor 47 (Fig. 7) is deposited between lobe 48 of capacitor plate 2b (Fig. 7) and circular metal deposit 49, the latter being the contact for the control-grid socket of the second valve.

An interesting feature of this system of producing a circuit arrangement is the facility enjoyed by the designer in screening certain sensitive points from induced hum or unwanted leakage currents and similar interference factors. A good example is shown at 50 (Fig. 7) where a metal deposit going right to the side of the panel and attached to the sockets of the cathode pin of the second valve (a relatively hum-free electrode) is used to screen the grid coupling capacitor 2b of this same valve from the influence, by leakage or external radiation, of the adjacent heater-filament contact pin, which is a point having a very intense hum voltage. Similarly, on the other side of the panel the other plate 2a of this same capacitor and its lobe 6 are screened from the humming points by the peculiar configuration of the main earthing electrode 7. (This part of 7 is marked 9 on Fig. 6.) At the same time, it acts as the means of interconnecting the earthing parts of this plate with the earthing parts of the other plate (see Fig. 18).

The point 51 (Fig. 7) is connected by way of metal path 52 to point 53. Path 52 has a high hum voltage, hence it is taken round outside the earthing electrode 7, so that the latter screens it from sensitive points. Coming back to the resistor 44, which is the grid-leak of the second valve and hence also sensitive to hum, this is likewise arranged to be screened by non-humming deposits 7 and 3b (see Fig. 7). Metal deposit 54 in Fig. 7 is an interconnecting path for cathode and suppressor grid and one heater pin of the first valve (see Fig. 8), as well as an earthing screen member shielding the hum-sensitive anode circuit of this same valve from humming point 51.

Considering Fig. 8 only, we now see that except for items such as valves, electrolytic capacitors and loudspeaker, we have made every component. Whilst this involves preparatory design considerations, it requires only a few actual production operations which can be listed as follows :—

(1) Moulding the plate (Fig. 3).
(2) Metallizing the same all over.
(3) Milling the surface of the plate to obtain the condition shown in Fig. 4.
(4) Spraying one graphite mixture through spaces on the surface of the plate shown in Fig. 6.
(5) Spraying another graphite mixture on the side of the plate shown in Fig. 7. Thus, fifteen electrical components, all of individual character and electrical value and in their correct location, and more than thirty-five conducting paths, all in their correct location and in contact with these components, have become one interrelated circuit.

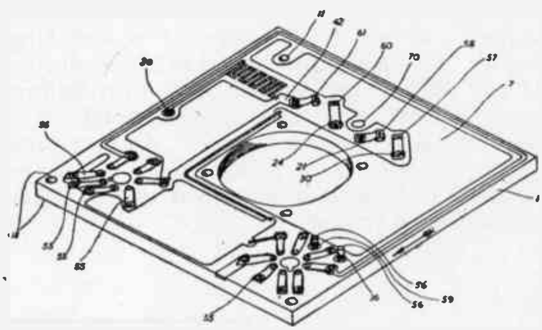


Fig. 9.—Here the sockets and eyelets have been inserted.

Facility is now required to plug in the prefabricated components, such as valves, which cannot be made by this method. This is facilitated by inserting eyelets, sockets, or similar items, as shown in Fig. 9. As these are in definitely prearranged positions automatic insertion of these small items and automatic eyeleting, riveting and similar operations become feasible.

Figure 9 shows the same side of the plate as Fig. 7. At point 20 an eyelet is inserted through the plate to act as an interconnection from conductors on both sides of the plate. At points marked 55 suitably shaped metal eyelet tags are inserted so that they radiate conveniently from whichever direction they happen to come, into the valve pin socket holes arranged in a circle around the key-way hole (mentioned earlier) to act in combination as the valve holders. These tags are

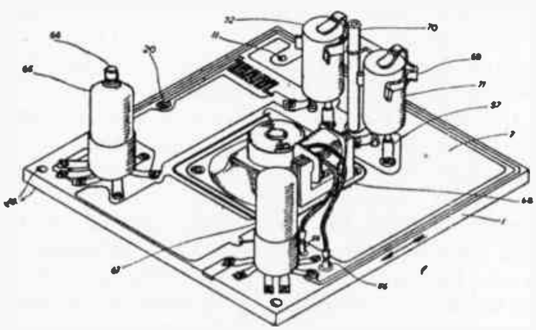


Fig. 10.—The parts that cannot be made by the process, such as valves, speaker and electrolytic capacitors are inserted in their respective positions.

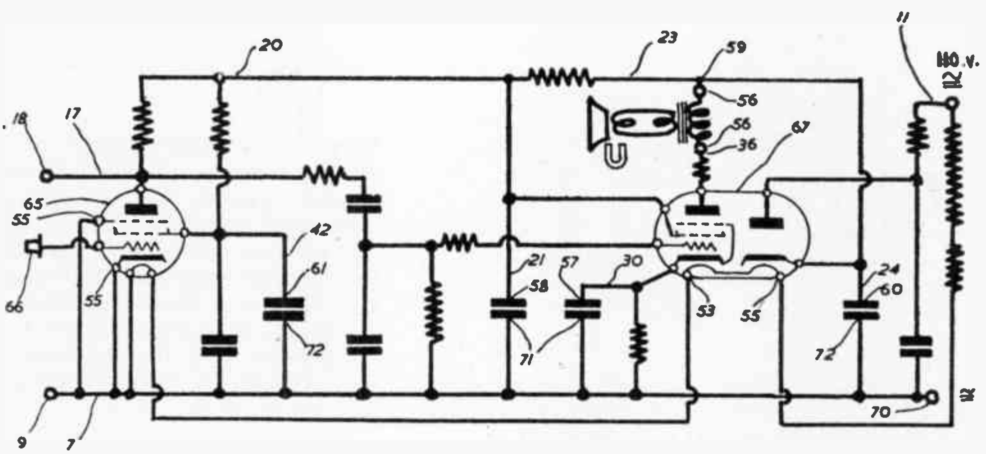
not numbered, though all are shown, and they are deliberately drawn in a slightly bent and irregular line to represent more clearly that they are springy parts attached on top of the moulding and not actually part of the moulding. Sockets 56 for the two loudspeaker connections are inserted into circular metal deposits 36 and 59 shown in Figs. 6, (see Fig. 3) to act as sockets for the positive terminal plugs of electrolytic plug-in capacitors. The function of each becomes clear from Figs. 6, 7, 8, 9, 10 and 11.

Protecting Circuit Deposit

It is preferable to spray the panel shown in Fig. 9 with lacquer to protect the deposited circuit, the relevant electrical connection and sockets being, of course, masked during the lacquering operation. This plate is now ready to have the prefabricated components plugged in as shown in Fig. 10. The valve marked 65 is the first valve, and has its grid terminal 66 on top to facilitate its connection to the second plate (to be described later), which carries the aerial input circuits.

The valve marked 67 is of the type containing an output system as well as a rectifier system. The loudspeaker 68 contains its own output transformer and is of the permanent magnet moving coil type. It is affixed to the main plate by quick-fix screws or rivets, and the output transformer leads are directly plugged into the two sockets 56 without the aid of individual soldering tags. This, again, avoids the usual soldering operation. The output transformer is, of course, provided with suitable flexible lead ends of the type normally used in light current electrical apparatus. The combination spring and earthing clip 69 shown mounted on the distance pillar 70 (Fig. 10) is mounted right into

Fig. 11.—Circuit diagram, similar to Figs. 5 and 8, of the complete amplifier shown in Fig. 10.



9 and 11. Specially shaped springy sockets 57 and 58, 60 and 61 are inserted into holes, and cavities 30, 21, 24 and 42 formed in the plate, which have been previously provided in the metal deposit paths the large main earthing metal deposit 7 at the hole 70 (Fig. 9). This distance pillar 70 acts as a support for the second plate and as a further earth return lead for the tuning circuit, on the second

plate (Figs. 12 and 13) and also serves as the negative return by way of the spring 69 from the body or case and negative terminals of the electrolytic 71 and 72. These capacitors each contain a

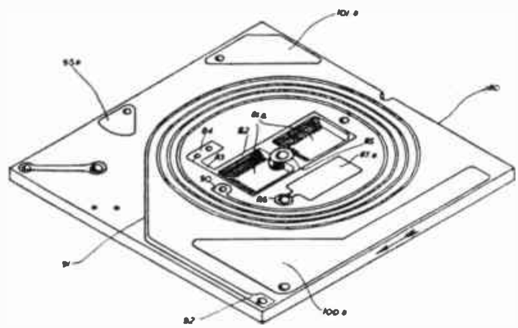


Fig. 12.—One side of moulded insulated plate before processing. After metallizing the grooves and depressions will form interconnected circuit comprising inductor and capacitors.

large and a small capacitor, the circuit being so designed and the clips 57, 58, 60 and 61 (Fig. 9) so laid out, that it is impossible to plug in these dissimilar twin capacitors the wrong way round. This combination becomes more clear when considering the complete circuit (Fig. 22). In Fig. 11 the conventional method of showing the completed circuit all in full line has been adopted, it being no longer necessary to differentiate between the top or under side of the panel.

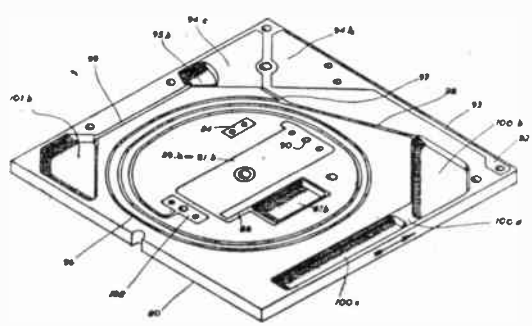


Fig. 13.—Perspective view of another moulded plate adapted to become the regenerative tuned circuit to be combined with amplifier shown in Fig. 11.

It will further be noted that this plate now comprises a two-valve amplifier and rectifier unit ready for use on A.C. or D.C. mains. The only addition required, of course, is the input means of a microphone and battery, the latter being arranged also to bias the open grid 66 of the first valve.

One side of the second plate 80 is shown in Fig. 12 and the other side in Fig. 13. This also is a moulding with deep indentations and grooves filled in with metal. In this case, in addition to capacitors, conductors, resistors and terminations it also contains inductors. These are located on both sides (Figs. 12 and 13) and are inductively coupled to each other through the plastic material of the plate. For convenience of illustration and for greater clarity, the inductor coils are symbolically shown with only a very few spiral turns on each side. In actual practice, of course, the number of turns on each would depend on the band of frequencies the receiver is intended to cover. For medium-wave broadcasting stations the coil on the face shown in Fig. 12 would have about twenty-five turns and that shown in Fig. 13 about seven turns.

Figure 14 shows the diagrammatic scheme drawn again according to the convention previously adopted. By comparing Figs. 12 and 13 with Fig. 14, the function of each part will become clear.

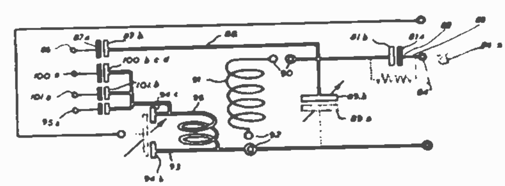


Fig. 14.—The circuit of Figs. 12 and 13.

Figure 15 shows the same side of this plate as Fig. 13, but after the graphite deposit 103 has been applied. Figure 16 shows the same side after metal sockets, pillars, clips and moving capacitor vanes (including insulation) have been affixed, and Fig. 17 shows the completed circuit of this plate. By reference to Fig. 18 and the left-hand portion of Fig. 22, the manner in which this plate (Fig. 16) co-operates with the previously described two-valve amplifier to form a complete radio receiver will become clear.

In Fig. 12 it is assumed that a moulded plate has been metallized and ground off on both sides, leaving the metal deposits in those parts lying beneath the surface level. Two deep square recesses 81a are located in the area covered by a shallow indentation 82. This interconnects them and shallow groove 83 and 84. These are all collectively metallized and are associated through two holes with a metallized indentation also shown as 84 in Fig. 13. From Figs. 14, 16, 17 and 22, it will be seen that this group of metal deposits form the capacitor plate which will be ultimately associated with the input grid of the first valve by way of the spring contacts 84s (Fig. 16). The circular surface area 85 (Fig. 12) in the midst of this metal deposit is left unmetallized and is an insulating area containing a threaded hole for the screw shaft of the variable tuning capacitor.

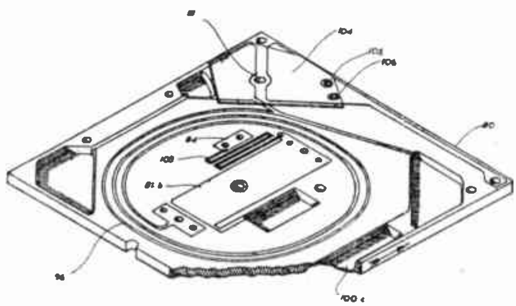


Fig. 15.—A fragmentary view of the plate in Fig. 13 after resistors have been deposited.

The other pole of the fixed capacitor 81b is clearly seen in Fig. 13, but it will be seen from Fig. 14 that it is intimately connected to the stationary plate 89b of the variable tuning capacitor, and hence, in this actual design, Fig. 13, one and the same metal deposit constitutes a plate for both capacitors. Therefore, in the drawing it is indicated by both 81b and 89b. From Fig. 14 it will also be seen that one of the poles of the aerial feed capacitor 87b is electrically connected to the above capacitor pole by metal path 88. The actual position of 88 is shown in Fig. 13 and the other pole of this capacitor 87a (Fig. 14) appears also as 87a in Fig. 12. The aerial socket 86 (Fig. 14), for the insertion of a plug attached to a low capacity small indoor aerial, will ultimately become affixed as shown in Fig. 16.

Figure 14 also shows that the interrelated metallized deposit system, consisting of capacitor plates 81b, 89b and 87b and conductor path 88, is also united to socket 90 so as to connect to the main tuning coil 91 on the other side of the plate. This is accomplished quite simply by providing a small hole 90 (Fig. 13) communicating with the lobe 90 (Fig. 12) which is the inside end of the spiral metal deposit inductance coil 91 (Fig. 12). This same hole 90 will ultimately contain a contact eyelet (or quick-fix screw) to attach this capacitor pole to any further spring leaf type capacitor vanes it is necessary to attach, so as to increase the capacity of the variable capacitor 89b and 89s in the usual manner.

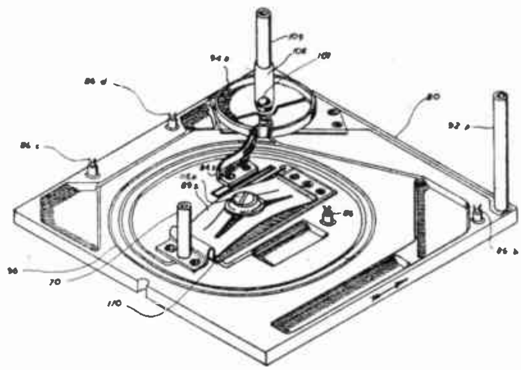


Fig. 16.—The plate with sockets, springs, variable capacitor plates and distance pillars inserted.

The inductor 91 (Fig. 14), in practice, is a spiral coil 91 shown in Fig. 12 running from an inside termination lobe 90 to its outside termination lobe 92. This lobe is interrelated with another termination lobe on the other side of the plate shown in Fig. 13 is also indicated as 92. The small round hole in metallized termination lobe 92 will contain a fixing screw or contact eyelet connecting it, by way of a pillar 92p (Fig. 16), with a metallized termination lobe 9 in Fig. 6, which is in the other plate (previously described) and acts as one of the earth return conductor paths. This is more clearly seen in Fig. 18. A conductor path 93 runs from termination lobe 92 (Fig. 13) and is widened out

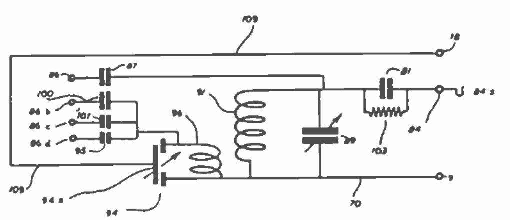


Fig. 17.—The completed circuit of plate shown in Fig. 16.

at its other end to form one of the stationary capacitor poles 94b of the rotary differential capacitor shown in Fig. 17 as 94. The other stationary pole of this differential capacitor is

94c (Fig. 13). From Fig. 15 it will be seen that this is electrically connected to one pole of an aerial feed capacitor 95b. In the embodiment shown in Fig. 13, 95b is an integral part of the metal deposit of the previously mentioned capacitor plate 94c.

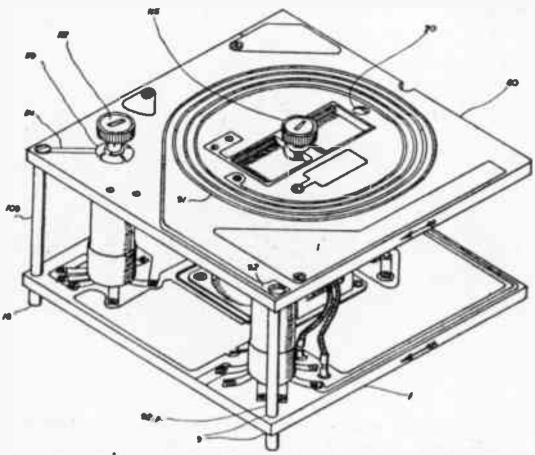


Fig. 18—*Complete all mains* (110*V.*) *broadcast receiver made by combining plates shown in Figs.* 10 *and* 16.

The other pole of this very small capacitor is shown in Fig. 12 as 95a and is designed to be connected to a long, large-capacity aerial, such as a telephone line for wire-borne radio frequency currents. It is inductively coupled to the main tuning circuit consisting of inductor 91 and capacitor (Fig. 17) through the smaller inductor coil 96. The actual interrelation between capacitor 95 and inductor 96 is clearly shown at 98, where a conductor path interconnects 94c (including 95b) with coil 96. The same metal deposit also continues in metal paths 98 and 99 to associate with similar, but larger, aerial feed capacitor plates 100b and 101b. Their other plates in position are 100a and 101a, respectively, shown in Fig. 12. These capacitors serve a similar purpose to capacitor 95 (see Fig. 17), but are intended to match somewhat smaller capacity aerials or land lines. A noteworthy point in the design of capacitor 100 is that it is an example where the designer can utilize peculiar shaped capacitors to fill in odd-shaped spaces left on the plate by other elements such as spiral coils. The elongation of the deep indentation 100c, Figs. 13 and 15, would weaken the panel 80, and hence the cavity may be sub-divided by a ridge under shallow indentation 100d (Fig. 13).

A further useful design feature is shown at the inside end 102 of the spiral metal deposit 96. This large deposit is not a capacitor element, but a large contact area to which a spring-like flexible variable capacitor vane 89a (Figs. 14 and 16) is eyeleted to the two outer holes of 102, the middle hole serving for the insertion of a screw to hold the second earth return by way of the pillar 70 (Fig. 10).

In order to connect the two earthed points, one on the outside and the other on the inside of the inductor, pole 92 (Fig. 13) is connected, by way of pillar 70, with deposits 7 and 9 on the other plate. By this means otherwise impossible connections can be achieved. It should be mentioned that when this is not practicable, resort can be made to a method of depositing metal across a previously deposited inductor, a film of insulating material such as lacquer serving as a bridge across lower lying conductors.

Figure 15 is a fragment of the same plate 80 as in Fig. 13 with the addition of the high value grid leak 103 across capacitor 81 (Fig. 17) deposited in any convenient shape so that at its ends it overlays a lobe of metal deposit 81b and contact deposit 84. Figure 15 also shows the addition of a separate plate of dielectric material 104, for the rotary capacitor depicted as if it were transparent, e.g. mica. It is preferably fixed with eyelets 105 and 106 to the plate 80. Under certain circumstances this also can be a sprayed-on hard dielectric film.

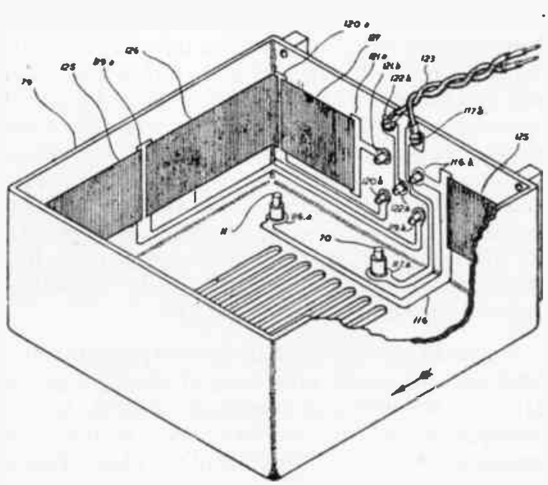
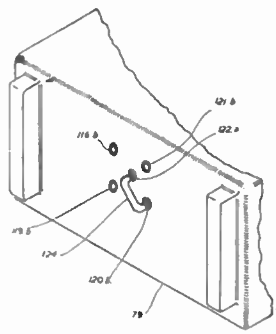


Fig. 19.—*Moulded cabinet (shown face downwards) processed to enable the broadcast receiver to function at various voltages up to* 250*V.*

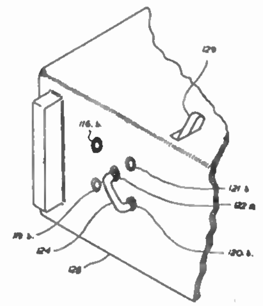
Figure 16 shows (*a*) the same side of the plate 80 as in Figs. 13 and 15, but completed by the insertion of eyelet sockets 86, 86b, 86c and 86d, shown also diagrammatically in Fig. 17 ; (*b*) valve input control grid contact springs 84s (also Fig 17);. (*c*) the dielectric plate (or plates) 110 for springy expansion capacitor plate 89a likewise eyeleted ; (*d*) the rotary differential capacitor 94a and its shaft which protrudes through hole 11 shown as a die-casting in Fig. 15 ; (*e*) the earthing pillar 109 supporting also a leaf spring 108, which presses upon a steel ball 107 to provide a smooth contact with the rotary capacitor vane 94a. The latter pillar 109 is more clearly seen in Fig. 16. Here it will be seen as a pillar inter-connecting spring washer 113 by way of conductor path 114, with plate 1 by way of fixing and contact hole 18 seen also in Fig. 6. This pillar 109 brings the radio frequency currents which have been amplified by the first valve at point 17 (Fig. 22) to act by way of coil 96 in an inductively regenerative sense upon the tuned circuit consisting of coil 91 and the capacitor 89 (Figs. 17 and 22). It should be noted that this regenerative sense is achieved in the design of the moulding tool which produces the plate 80, the mutual inductance having a predetermined sense, and thus avoids an error that so often occurs in the manufacture of coils. Figure 18 also shows the main tuning capacitor knob 115 which is attached to a screw 115a (Fig. 16) in threaded hole 85 (Fig. 12) and which when rotated several times compresses spring leaf 89a (Fig. 16) against mica 110 (Fig. 16) and metal deposit 81b (Fig. 15), thereby increasing the value of the variable tuning capacitor 89. Both knobs 112 and 115 (Fig. 18) are assumed to be screwdriver operated semi-variable members.

The third interconnecting pillar 70 of the two plates 1 and 80 is not visible in Fig. 18, but its fixing screw (also marked 70) can be seen. The three pillars connect the two plates rigidly and provide a complete manufactured article in a functioning condition which can be affixed into any suitably shaped cabinet or built into some other apparatus.

The points at which the A.C. or D.C. voltage mains can be applied to this piece of apparatus are shown as contact strip 11 in Fig. 6 and point 70 on Fig. 6 (the latter communicates with the entire deposit marked 7). An example of such a cabinet 79 is shown in Fig. 19, which is a broken perspective view in a position ready to receive the complete unit Fig. 18. (The arrow on the side of both Figs. 18 and 19 which has been used throughout will facilitate finding the parts which will interconnect when the complete unit of Fig. 18 is inserted into the cabinet.) Spring contact posts marked 70 and 11 in Fig. 19 register and connect with the corresponding points on plate 1 (Figs. 6 and 7). (Also, see points 11 and 70 in Fig. 22.)



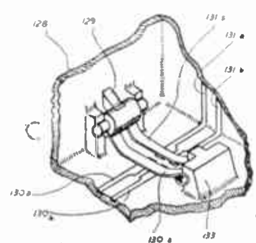
A



B

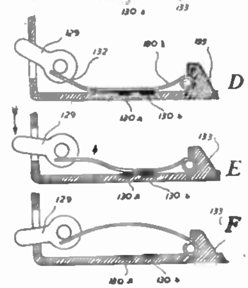
Fig. 20A.—The underside of the cabinet showing mains adjustment tapping link.

Fig. 20B.—An alternative cabinet arrangement incorporating a main switch.



C

Fig. 20C.—Two deposited conductor circuits with switching arrangement.



Figs. 20D, E, F.—Depicts the action of the switch shown in Fig. 20C.

A convenient method of adapting a piece of electrical apparatus to other than a predetermined operating voltage is illustrated here, where a series of resistors and contact strips, tapping points and similar items, are all deposited in an inter-related manner on to the walls of the containing cabinet.

Figure 20A shows a fragment of a cabinet bottom 79. In Figs. 19 and 20A, plug-in sockets are shown, the corresponding ones bearing the same characters. In this case socket 122a in the centre (Fig. 20A) is electrically united with a metal deposit strip on the inside of the cabinet leading to point 122b to which one of the flexible mains leads 123 is attached. The link 124 in Fig. 20A is shown plugged into this control socket 122a and one of the tapping points 120b.

In Fig. 19 tapping point 120b is electrically united with deposited metallic tapping strip 120a. In a similar manner, socket 121b conducts to 121a; and 119b to 119a; and 116b to the spring post 116a. Over these deposited conductor strips there is a wide graphite coating consisting of a long deposition 125 on three sides of a cabinet and two shorter depositions 126 and 127. These are all shown on the complete circuit diagram Fig. 22 from which their function becomes clear. They are to extend the range of mains supply voltage of the apparatus in Fig. 18, from 110 volts to 250 volts, in suitable steps.

Figure 20B shows the bottom of a cabinet 128, produced by this technique, in which a double pole switch 129 is incorporated making direct contact with deposited metal. The toggle handle is a loose moulded insert of insulated material more clearly seen in Fig. 20C. The spring leaves 130s and 131s are supported in a spot 132 in the toggle 129 (more clearly seen in Fig. 20B) and in the recess in the moulded lug 133. The operation of such a simple switch can be seen from Figs. 20D, 20E and 20F. In position 20D the toggle hand is at rest in its upward position and spring 130s (whose natural free shape is flat) presses firmly on to the ends of the two deposited metal contacts 130a and 130b. Figure 20E shows the toggle in a downward motion and in an intermediate position. This first part of the movement causes only that part of the spring near itself to rise, and the circuit through the spring leaf is still in being. When, however, the toggle handle has been moved right down, the spring very suddenly jumps up into its other position of equilibrium as shown in Fig. 20F, causing a sudden separation from the contacts 130a and 130b and thus a sudden break of the circuit. This type of switch can be made to carry, in the arrangement shown, any load met in radio receiving apparatus and similar electrical apparatus.

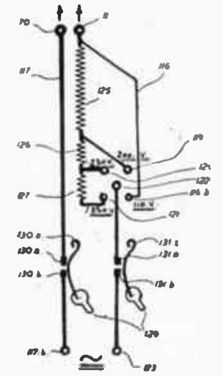


Fig. 21.—Diagram of the electrical parts of processed cabinet.

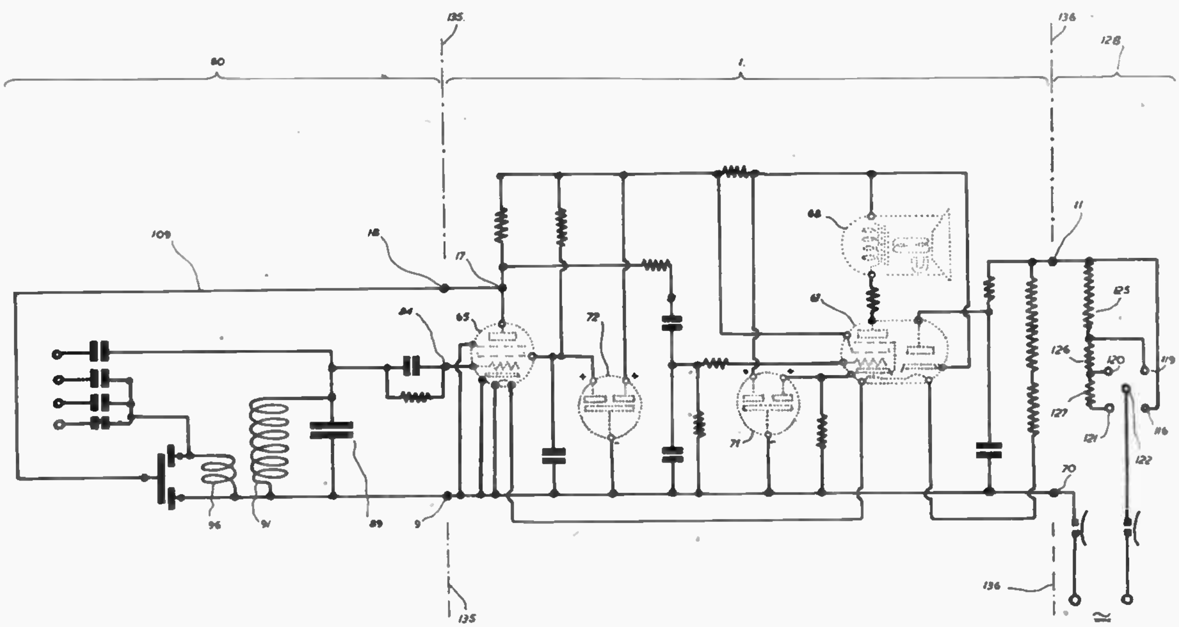


Fig. 22.—The completed circuit of the broadcast receiver made by combination of three basic parts.

Figure 21 shows a preferred circuit of such a cabinet with tapped, deposited series resistor and double pole mains supply switch. This shows output contacts 11 and 70 having the same significance as those shown in Fig. 19. All the other numbers have the same significance as those previously described in connection with Figs. 19 to 20F.

The purpose of Fig. 22 is to show the utility of this system. It shows in detail the complete circuit diagram of the instrument described from Figs. 3 to 21. The part to the left of the dot-dash line 135 is the circuit arrangement contained on the panel 80 described in connection with Figs. 12 to 17. This connects, by means of points 18, 84 and 9, with the circuit arrangement between lines 135 and 136, contained on plate 1, described in connection with Figs. 3 to 11, these combining to give the circuit of Fig. 18, which connects up via points 11 and 70 with the circuit contained in part 128 (or 79), Figs. 19 to 21.

From this it will be seen that an interrelated electrical circuit arrangement has been provided by a rapid and economical production procedure. In the example given, the interrelated deposits avoid the need for assembling in the normal way some 30 *individual component parts and the making of over* 80 *hand-soldered connections. In no case can the deposited circuit become incorrectly wired because if the deposit is in existence at all it must be the correct circuit. By this method of design with aid of a minimum number of prefabricated components such as valves, complete apparatus can be produced without the use of wire or soldering. Moreover, the attendant multitude of manual operations involved in the normal methods of manufacture are eliminated.*

It is obvious that this system can also be applied to the production of more elaborate electrical apparatus than a radio receiver. It is also clear that even if only part of such apparatus is made in this manner and other parts by more orthodox methods, the utility and economy achieved are substantial. The degree to which the designer will choose to make use of this will be governed by the magnitude of the production programme and is mainly one of the economics. Generally speaking, the larger the production programme the more it will pay to adopt this conception in the design features of the product. Where several models, for example, of a certain electrical or radio instrument are made, having certain parts identical, it will be good economy to make that identica part of the instrument in this manner and incorporate it in the complete apparatus as if it were a composite component or sub-assembly. Such sub-assembly plates or groups of plates can be plugged or wired into the whole apparatus in the normal way.

Section 3. FURTHER APPLICATIONS

Certain features arising from the foregoing will now be described, by way of example, as guidance to designers.

Figure 23C (p. 18) shows an inductor coil 141 in which a spiral deposit is provided on both sides of the plate 141a and 141b, interconnection between the inside spiral turn of each, in this case is provided by the eyelet 142. The semi-variable capacitor 143 (Fig. 23B) for tuning this circuit to the exact fixed frequency required has its two plates 143a and 143b (Figs. 23A and 23C) directly interrelated with the two outside spirals of the inductor. Eyeleted into the deposit 143a (with the same eyelets 144 and 145 holding the valve sockets of the earthing contacts of the self-contained valve holder) is the variable earthing incremental plate of capacitor 143 consisting of spring plate 143s (Figs. 23A and 23C). This is positioned with reference to a lug-shaped deposit 143c in the underside cavity of the plate 140 in the usual manner by screw 146. It will be noted that the dielectric of this capacitor 143 consists partly of the web of insulating moulded panel substance, made as thin as possible (see 140w, Fig. 23C) and partly of air. As the stationary deposited capacitor plate 143b requires to be electrically connected to one pole of the fixed capacitor 147 (Fig. 23B), it is convenient to make this in one with the previously mentioned plate 143b ; hence the latter is simply enlarged as shown in Fig. 23A at 147b. From the circuit Fig. 23B the other plate of capacitor 147 requires to be connected to the diode of the valve and to have a high resistance leak to the earthing pole of the system.

The simple manner in which this is accomplished is shown at 147a (Fig. 23A), metal being deposited, and associated by lobe 148 (Fig. 23A) with the diode anode pin socket of the valve (Fig. 23B) and by another deposited lobe with resistance 149 deposited to overlap capacitor deposit 143a.

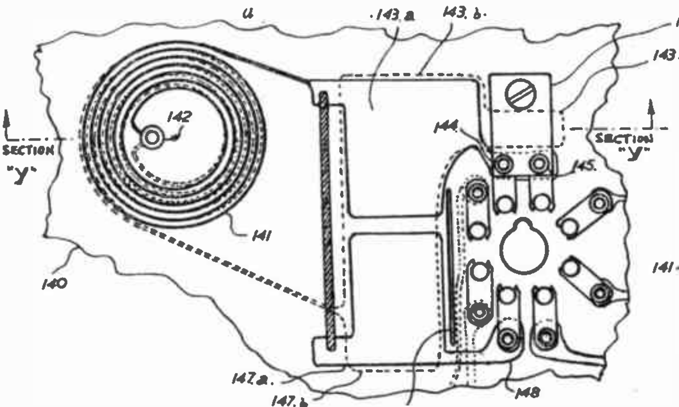


Fig. 23A (right).—A plan view of a fragment of the plate 140, *upon which an interrelated circuit network is provided.*

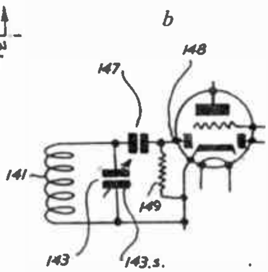


Fig. 23B (above).—Schematic arrangement of Fig. 23A.

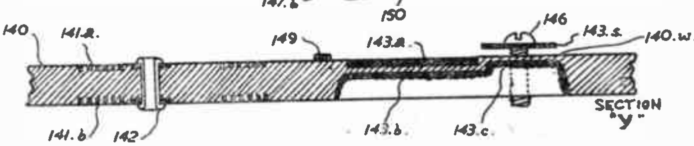


Fig. 23C is a cross-section view through the line "y" viewed in the direction of the arrow shown in Fig. 23A.

To reduce electrical interaction from surface or dielectric leakage of mechanically adjacent parts deposited on to a panel, but which electrically belong to different parts of the circuit, the moulded plate is provided with a narrow space 150 (Fig. 23A) like a saw-cut slot between such parts. This can have any suitable shape. In the metallizing operation this should be masked so that the slot remains empty. It is sometimes advantageous to fill such a slot with metal and allow it to be associated with an earthing part of the circuit and thus provide a screen. One can also have two slots, one of each kind.

Fig. 23C shows a method of transconnection (of circuit parts on one side of the plate with circuit parts on the other) by means of an eyelet 142. The previous descriptions of embodiment have all shown this method, but without departing from the system, many other methods of transconnection are possible.

Figure 24 shows in cross section several such methods. In this figure, *a* shows transconnection of the metal deposits on either side of the plate (shown black) by a thin rivet. This can be conveniently inserted by a special machine which pierces a hole, then inserts the end of a wire (carried as a coil on the machine), then cuts off the required length, and finally squeezes it to form the two rivet heads. This involves piercing a hole after the metal deposit has been made. An alternative is shown at *b*, where the thin hole is provided in the moulding by a tapered needle-shaped tool. A short length of wire is forced into this tapered hole and is either riveted over or even left as it is, whereupon the metal which is deposited into the grooves on either side becomes intimately transconnected. This is a method particularly advantageous when making tapping points to inductor coils.

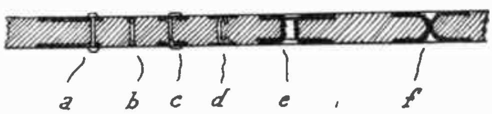


Fig. 24.—Other methods of transconnection.

At *c* is shown a variant of *a*, where, instead of riveting, the wire is clinched or bent over top and bottom. Another variant of *b* is shown at *d*, where the clinching is done before the metal deposit. If the apparatus is likely to be used in an atmosphere likely to contaminate purely pressure contacts, the transconnections can be made to cohere by the use of solder or a similar substance, or by welding.

The fact that the whole electrical circuit arrangement on one side of the plate is in a two dimensional plane permits the simultaneous soldering of all points at once. For instance, one can print (with a suitably shaped rubber stamp) right on to all parts requiring solder a colloidal suspension of tin, preferably containing a flux in the suspending medium, or a suitable soldering alloy and then heat up the whole plate, when all points will simultaneously cohere to the associated metal deposits.

Two methods are shown at *e* and *f* of completely avoiding the need for transconnection of the metal deposits by a separate operation with a separate metallic part. The moulded plate itself, shown in cross section, has a round hole or narrow oblong slot moulded into it, and when the molten metal is sprayed on to both sides of the plate sufficient metal will penetrate to cohere with that on the other side to provide a transconnection conductor. At *f* is shown the hole funnel shaped on both sides to make sure that the actual contact is not positioned in a random manner but in a fixed place. (This is especially useful for short wave inductors where the length of an inductor must be exact to very small limits.)

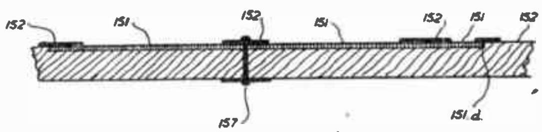


Fig. 25.—Cross sectional view of an example where the sequence of operation is reversed.

Fig. 25 shows a cross sectional view of an example where the sequence of operation hitherto mentioned, i.e. first metallizing and then depositing the resistive material, is reversed.

This is particularly useful in connection with the deposition of complicated resistive networks (such as occur in oscilloscopes and television apparatus) and the graphite 151, shown with vertical shading, is first deposited on to the plate and can be applied into moulded smooth depressions 151d. (It is known that graphite resistors will deposit more evenly, and hence more uniformly, if applied to a polished surface, and this method avoids the preliminary lacquering operation.) The metal layer 152, shown in black, may be conveniently printed on with conductive paint as the lower conductivity of metallic paint, compared with a metal sprayed deposit, is completely negligible as such, since the resistor network usually consists of elements having values of the order of megohms. This method of inverting the deposition sequence is also useful when depositing a resistive network containing fixed, as well as variable resistors or potentiometers (153 and 154, Fig. 39 p. 26), such as the portion of the lay-out arrangement shown on the rearmost plate 155 (Fig. 39) which illustrates an oscillograph or television receiver embodying this system. The sliding contact (or wiper arm) 156 (Fig. 39) is of the usual construction and slides with light pressure on the deposited resistor material. A transconnection is shown symbolically at 157 in Fig. 25.

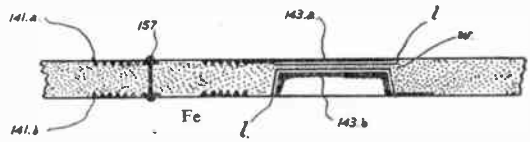


Fig. 26.—Shows a method of increasing the inductances of a given shaped inductor (e.g. grooved spiral system)

Figure 26 shows a method of increasing the inductances of a given shaped (e.g. grooved spiral system) inductor such as occurs in the device depicted in Figs. 23A and 23C. Here, the whole plate is made of moulded plastic material in which the filler contains a high proportion of molecular iron dust or other material imparting a high permeability to the substance, shown as an area filled with dots and marked Fe in Figs. 26 and 27. It will be noted that, due to the separation of the iron molecules by an insulating film in the solidified moulding, such a plate is non-conductive in the normal sense. However, it is difficult to make a very thin film act as the web or diaphragm of a fixed capacitor, and hence the fixed capacitors are either deposited entirely on one surface with sprayed lacquer dielectric and stencil sprayed second capacitor plate or, as depicted in Fig. 26, the web *w* is strengthened by being sprayed with a thin coat of lacquer. This powdered iron dust in the actual web acts as an extension of the other capacitor plate and increases its value. It is only in this sense that the molecular iron acts as a conductor.

In Fig. 26 this lacquer layer is shown white on both sides of the web and is marked *l*. The metallization marked black is deposited into depressions or printed on to the plain surface.

In view of the fact that the presence of molecular iron in some parts of the circuit is unwanted and is also much more expensive than other fillers, it is better to mould the main plate of a plastic substance and squeeze into a previously prepared cavity 158 (shown in Fig. 27) a limited amount of plastic with molecular iron dust filler. It is advantageous only partly to cure the main plate before this material is squeezed in and then completely cure with the spiral coil grooves and depressions simultaneously moulded across the boundary between normal filler and iron filler. Furthermore, it is preferable to use the same basic plastic substance for both parts so that the whole mass coheres to form a solid body. It is preferable to use pellets with dissimilar filler placed in their proper places in the mould before compression.

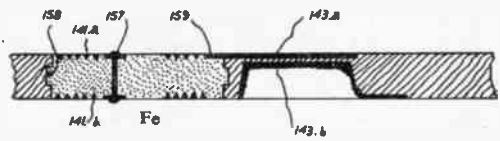


Fig. 27.—Section of a moulded plate, part of which is filled with iron dust.

It should be mentioned that in the same manner that part of the plate can be moulded with a filler containing different electro-magnetic properties, it can also have a part containing a substance having different electro-static properties such as specially high dielectric properties. Parts can also be moulded with a filler containing a high resistance material, such as carbon or silicon, or a filler containing some other desired electro-physical property. The main feature of such a combination of base materials being that the circuit deposits on the surfaces of the plate are provided in an interrelated manner achieving the production economy above mentioned.

It may sometimes be an advantage not to deposit the metal conductors in grooves, or just on the plain surface, but actually on protuberances or ridges. This may be advantageous where the apparatus has to work in humid atmospheres and where an arrangement in grooves or on a flat surface may produce surface leakage troubles. Also, in transmitting equipment the higher power employed may make it desirable to carry the conductors on ridges.

In such circumstances the metal can be deposited on the ridges (see 160a Fig. 28 and protuberances 161), by using the specially prepared moulding as if it were a printer's line block and contacting it with a pad saturated in conductive ink (e.g. colloidal graphite), allowing this to dry and then electro-plating it with metal. The resistors can next be applied by printing technique into the lower lying wide spaces. Figure 28 also shows a feature of arranging the capacitor blade inside the cavity in the form of an eyeleted plate. This feature is useful if it is required to have several capacitor plates adjacent to each other inside a deep depression, and it would not be easy to keep these separate if the spraying method were employed.

The type of arrangement shown in Fig. 28 is also useful if it is desired to make the whole plate of a heat-resisting substance, e.g. a ceramic material such as "Frequentite." Here, the metal deposit constituting the interrelated circuit network consisting of resistive, capacitative and inductive components or parts of components, can be produced on the ridges by using the ceramic plate as the printing block. Ink consisting of a suitable compound of silver, such as is used in pottery work for decorative purposes is suitable, and will decompose into metallic silver on being fired.

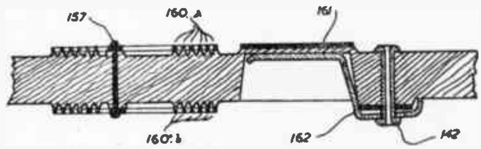


Fig. 28.—Section of moulded plate showing metal deposited on ridges and protuberances.

As further examples of useful design features, Fig. 29A shows a plan view of a plate fragment 163 carrying a capacitatively coupled fixed-frequency band-pass filter. This is shown diagrammatically in Fig. 29B.

Obviously, this can be made semi-variable as in Fig. 23A if more accurate resonance is required than can be provided by the tooled-up moulded depressions. The two inductors 164 and 165, consisting of double-sided spirals, are directly interrelated with capacitor systems, whereby plate 166a and 167a is one deposit and serves, at the same time, as a plate of the resonating capacitor 166 and 167. The other pole of the resonating capacitor 166 is shown as a dotted oblong marked 166b. The metal deposit representing the other pole 167b (shown as a dotted oblong) is enlarged, and acts also as the bottom plate 168b of the second resonating capacitor 168. Its lower elongation also acts as one pole 169b of a further coupling capacitor on top and is shown in full lines. The resistive component 170 is deposited quite simply across any suitable place where a lobe 171 is arranged.

Figures 30A and 30B (p.22) shows a similar embodiment and, together, are easily understood from previous explanations. They represent an example of a partly inductively coupled band-pass filter, the same numerals being used in these figures as in Fig. 29A and Fig 29B where possible.

length which, when eyeleted into place by large eyelet 172, will predetermine the exact degree of coupling. This pillar can also be a right- and left-hand screwed nut by which the coupling can be adjusted by varying the distance between the plates.

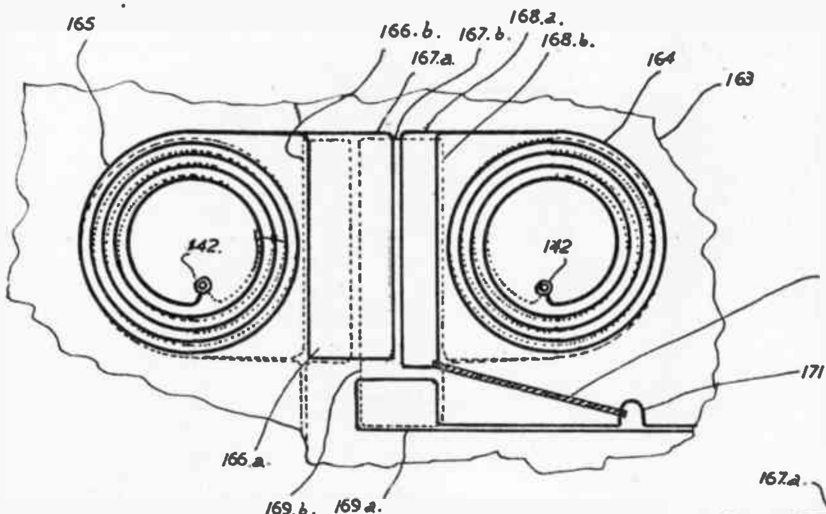


Fig. 29A (above).—Plan view of plate fragment carrying capacitatively coupled band-pass filter.

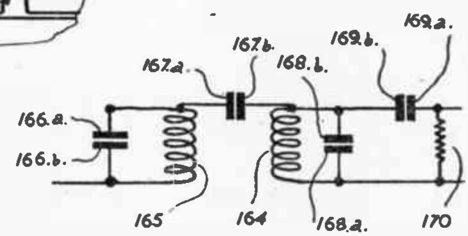


Fig. 29B (right).—Schematic arrangement of Fig. 29A.

However, by allowing the coils to overlap as indicated at " M," mutual inductance of a definite predetermined amount is provided as also is a capacitative coupling of small magnitude marked dotted as 167 (Fig. 30B).

By arranging in the design the direction of the spiral turns it is possible to predetermine whether this predetermined capacitative coupling will aid, or detract from, the inductive coupling. It will thus be of value in determining the resultant band-pass characteristic which will be maintained in production, it being quite independent of human agency. Thus, it will not be subject to human error, a trouble frequently experienced in normal coil winding.

Figure 31 shows a cross sectional view of another alternative method of coupling two deposited interrelated circuit networks. Only the inductive elements 164 and 165 are shown here. The usual transconnecting eyelet is represented by 142, whilst *p* is a pillar which can be made to an accurate

Figure 32 (p. 23) shows another alternative where a powdered iron screw core 173 is used for varying the inductances and the coupling. In this figure the transconnection 157 is shown as made by the method described in Fig. 24. If the apparatus requires parts of the circuit to be changed for different purposes, this can be accomplished in many ways which only differ from each other in the particular method employed.

This will be understood from one example described in connection with Fig. 33A (p. 23) which shows a plan view of a plate fragment carrying the circuit of an oscillator valve and having means for switching it to eight distinct wave bands by hand operation.

The basic circuit, which is of a " Colpitt's " oscillator, is shown in Fig. 33B. The portion of the main plate 175 is presumed to carry the main circuit of the apparatus whose band of operating frequencies it is desired to alter in distinct steps.

This plate contains a large clearance hole 176 in which a disc plate 177 is arranged to rotate freely, it being carried on an operating shaft (not shown) mounted through hole 178 and suitable bearings. The free rotation of this disc is restricted by spring 179, which locks into notches as shown at 180. A fragment of only about a half of this disc 177 is shown, but the whole disc would contain four double spiral inductors marked 141 transconnected at their inside end by eyelets 142, as previously explained in relation to Fig. 23A. Their outside ends are directly interrelated with long arc-shaped contact deposits shown at 181a on top and 181g on the bottom, shown dotted. It will be noticed that these deposits are slightly staggered, the reason for which will be made clear hereafter. At the sides of each coil are situated the associated pre-adjustable "trimmer" capacitors 182, of which one pole of each is wholly deposited and the other is a stamped out sheet-metal segment.

The metal segment of the "trimmer" capacitor actually engaged is shown at 182a and is adjustable by rotation with a screwdriver inserted into the screw head shown at 182h. Electrical contact to this metal segment is made by the metal deposit 183a which terminates at the edge of the disc in the form of a short arc-shaped deposit. The stationary plate of this trimmer capacitor 182s is shown dotted and is a deep indentation on the other side of the panel, similar to plate 143c of Fig. 23C. The metal deposit inside this cavity is interrelated by way of a shallow groove with short arc-like shallow deposit 183g at the edge of the

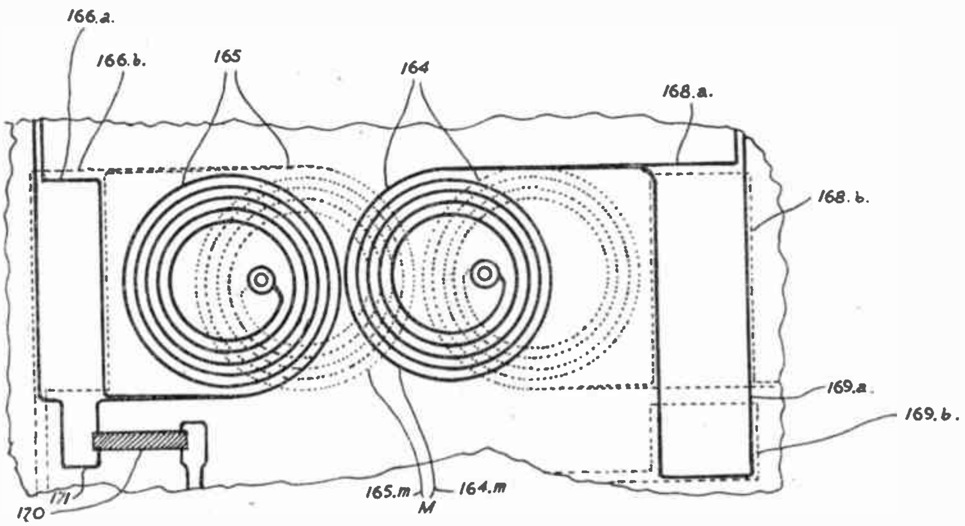


Fig. 30A (above).—Inductively coupled band-pass filter moulded on to a plate.

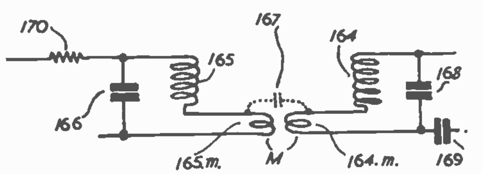


Fig. 30B (right).—Circuit of filter shown in 30A.

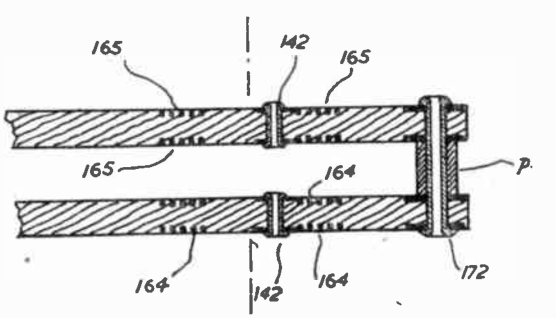


Fig. 31.—Cross sectional view of another alternative method of coupling two deposited interrelated circuit networks.

disc and acting as a switch contact. Contact arcs 181a and 183a make, in conjunction with the completely eyeleted lug, wiper type contacts indicated at *a* and *aa* respectively. Contact arc 181g and 183g shown dotted make with the slightly visible eyeleted lug wiper type contacts indicated at *g* and *gg* respectively. From Fig. 33B it will be seen that contacts *a* and *aa* go to the anode shown as A of the valve V, whilst contacts *g* and *gg* go to the grid of the valve marked G by way of an isolating capacitor 184. The latter is a fixed capacitor entirely consisting of metal deposited plates 184g and 184b. The grid leak 185 is of resistive material deposited across metal deposits *c*, the eyeleted socket connected to the cathode pin of the valve, and metal deposit G and the eyeleted socket connected to the grid pin of the valve. The fine adjustment to the various wavelengths within the band (i.e. so-called " band spreading ") is accomplished by rotating the variable double capacitor of the " Colpitt's " oscillator 186. This can be stamped sheet metal on a die cast disc with peculiar shaped openings *z* and *z*, or it can be a ceramic dish shaped member as used in a present-day trimmer capacitor with an interrelated double metal deposit whose peculiar shape is shown at

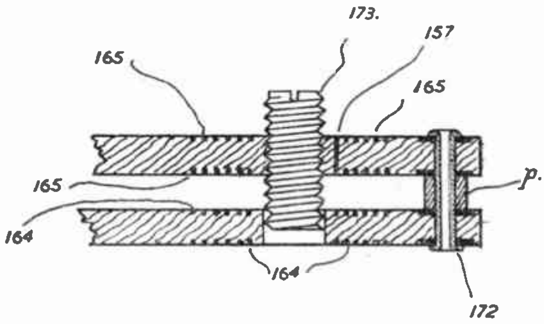


Fig. 32.—Showing a powdered iron screw core being used for varying the inductance and the coupling.

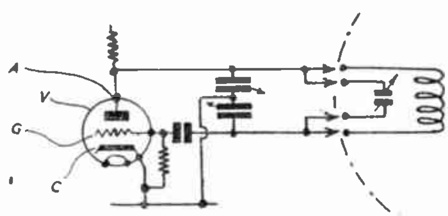


Fig. 33B.—Circuit arrangement of plate shown in Fig. 33A.

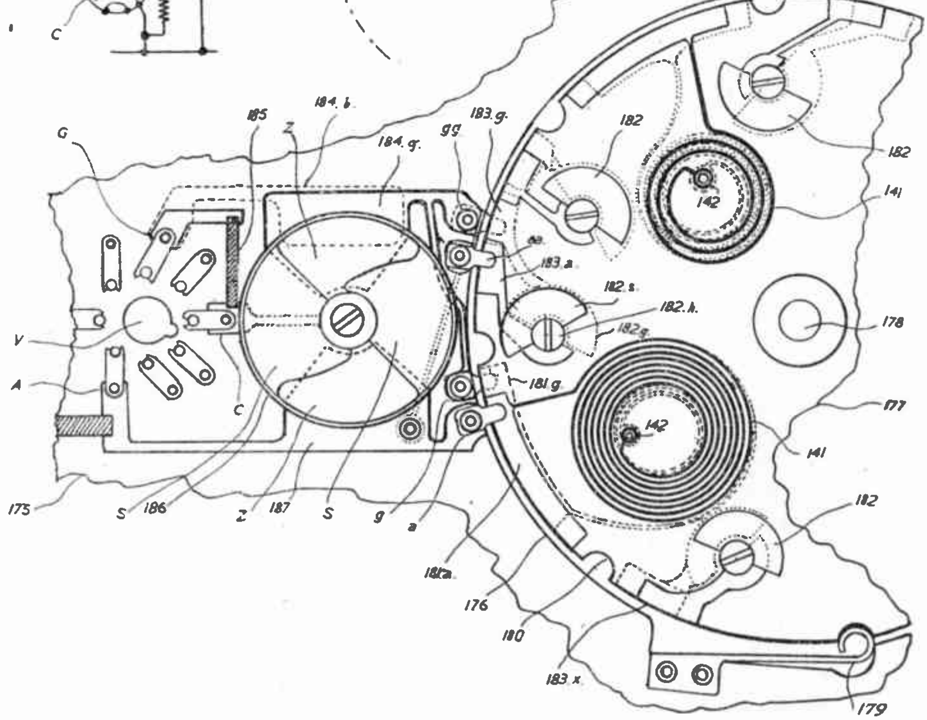


Fig. 33A.—Plan of plate fragment carrying an oscillator valve circuit.

s and *ss*. This simultaneously alters the anode-to-cathode capacitance as well as the grid-to-cathode capacitance of the circuit by affecting metal deposited capacitor plate 187 and 184g through a film of dielectric sprayed on to the top visible surface of the main plate 175.

When it is desired to change the wave band by a distinct step to a slightly different one, the disc 177 is rotated in a clockwise direction by shaft 178 to the next index position. The long arc-shaped coil

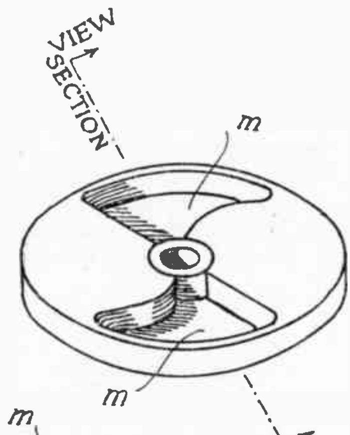


Fig. 34A.—Alternative method of making rotor for a variable capacitor.

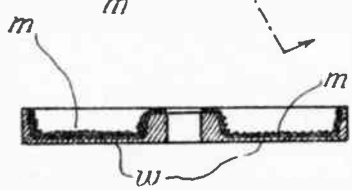


Fig. 34B.—Cross section through dotted line shown in 34A.

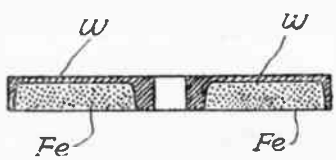


Fig. 34C.—Similar moulding to 34A with cavities filled with molecular iron core.

contact 181a which makes contact with wiper contact *a* will not " make " with wiper contact *aa*, not now in contact with the capacitor 182. This will have moved away in a clockwise direction, whilst the wiper contact *a* will engage the short arc contact 183x of another " trimmer " capacitor. The same procedure will have taken place with the contacts *g* and *gg*. Moving two notches will change the inductor also and cause a greater increase in waveband. The important feature which emerges from a consideration of Fig. 33A is that by the employment of this system it has been possible to make, by simple means, a highly complex electrical circuit which normally requires a great deal of human care and involves the use of many prefabricated components. Of course, more discs, such as 177, can be coupled together in various main panels spaced apart in a manner shown in Fig. 39 (p. 26), where the plates 192, 193 and 195 are interposed between the back plate 155 and the front of the cathode ray tube C.R.T. in the panel 191. This renders possible the changing of several circuits simultaneously.

Screening plates to reduce electro-magnetic coupling between adjacent discs containing coils such as 177 (Fig. 33A) can be deposited on to intermediate plates, 192 (Fig. 39), or mounted as metal screens between the plates. The former can contain other parts of the circuit such as deposited components associated with other valves 194. Some of these plates can be larger or smaller, a small plate being shown at 195 (Fig. 39). This gives various combinations, and some plates, such as those shown in Figs. 40B and 40C carrying parts which may require to be set at an angle (e.g. " Magic Eye " tuning indicator valve marked 196 in Fig. 40A) can be arranged to plug into each other by plugs 197g, 197h, 197s, 202, and 207 in Fig. 40B. Sockets can also be eyeleted into metallized deposited lobes so that the circuit arrangement on one plate 198 (Fig. 40A) becomes interrelated with the circuit on another plate 199 (Fig. 40A, p. 26).

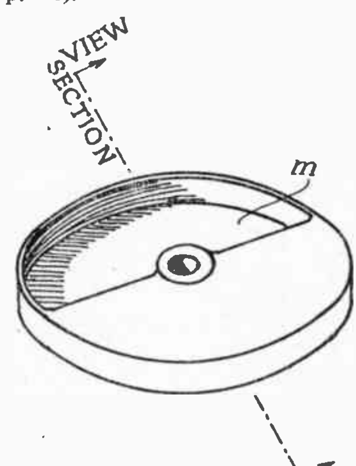


Fig. 35A.—Similar moulding as in 35A but arranged for a single or differential capacitor.

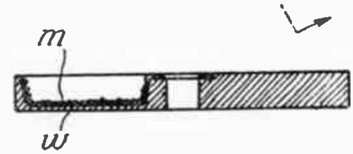


Fig. 35B.—Section through moulding shown in 35A.

A more simple variant of the above, still maintaining detachability, is shown in Fig. 40B (p. 26).

The relevant parts of Fig. 40B and Fig. 40C are annotated in a manner clearly explaining their import and are substantially the same as similar circuit elements described above.

Coming back to matters of detail, Fig. 34A shows an alternative method of making a moulding for the rotor of the variable double capacitor 186 in Fig. 33A.

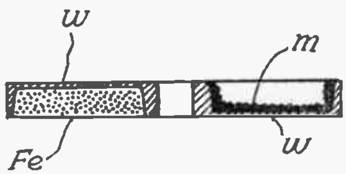


Fig. 36.—Showing moulding which combines the features of 34C and 35B.

A cross section through the dot-dash line in Fig. 34A is shown in 34B. This shows the upper surface of the rough metal as deposited by the spray gun. Here, it should be noted that the accuracy of the metal deposited electrical elements is determined by the shape and accuracy of the moulding or masking tools (in this case the mould) and not by thickness of the metal deposits which can be rough on the outside. The active part of this metal deposit *m* (Fig. 34B) is the surface which is in intimate contact with the dielectric web *w*. This surface is exactly the same on each moulding and is a function of the surface finish of the moulding tool. Figures 35A and 35B are similar mouldings, but for a single or differential capacitor such as used in Fig. 15.

Figure 34C shows a similar moulding to Fig. 34A, but here the cavities are filled with a molecular iron core filled plastic " Fe " which varies the inductances.

Figure 37A is a perspective view of a plate fragment which is shown in cross section in 37B. This plate has deposited upon it inductor 217, shown also as a double layer coil in the cross section. In order to increase the inductance value of the coil, two powdered iron cores of conventional design are inserted through apertures 219 in the plate. These two cores 218 form a closed magnetic path of known characteristics increasing the inductance value of the difference in permeability value of this core material to that of air.

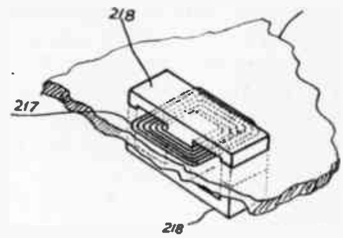


Fig. 37A.—Plate fragment on which an inductor is deposited.

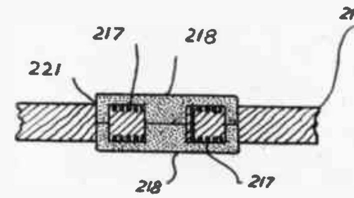


Fig. 37B.—Section moulding shown in 37A.

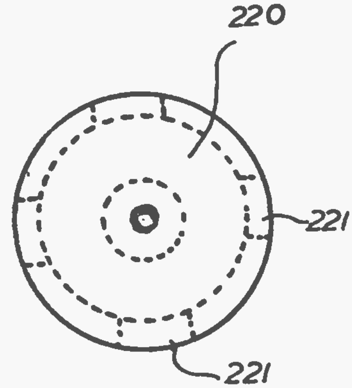


Fig. 37C.—Plan view of an improved core shape.

Fig. 37C shows the plan view of an improved core shape 220 to take the place of 218 in Fig. 37B. The part 220 has the same cross section as 218, but has four or more depending lugs 221, the shape of which is shown in Fig. 37B. The purpose of these is to increase the screening effect of the powdered iron core around the coil.

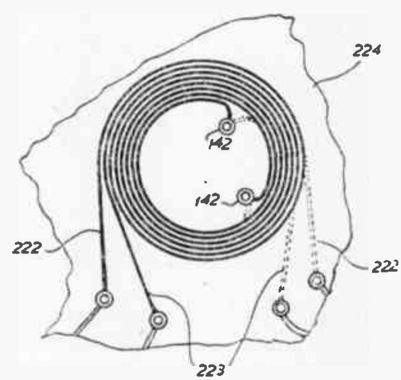


Fig. 38.—Plan of double spiral coils deposited on a moulded plate.

Figure 38 (p. 25) shows a plan view of double spiral coils, consisting of two electrically separate spirals 222 and 223 deposited on a plate 224. This device permits very intimate inductive coupling between two circuits. Such a coil deposit can, of course, be fitted with powdered iron cores in accordance with Figs. 37A, B and C.

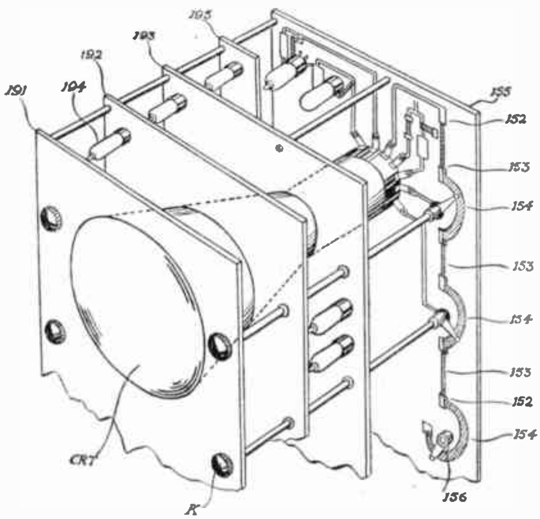


Fig. 39.—Tentative arrangement of several plates to form television set or oscillograph.

shows part of a plate 210 in which slots 211 are moulded. Metal deposit paths 212 are made in these, the molten metal being allowed to flow into the slots as described in connection with Figs. 24 E and F. This kind of arrangement would be useful

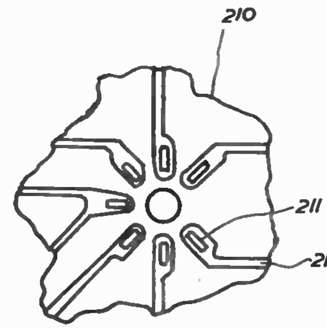


Fig. 41.—Slots are moulded into a plate to form base for a valve-holder in expandable equipment.

where only a very short functional life is expected of a valve and its circuit as, for instance, in apparatus used in meteorological balloons (which do not return) or special electronically controlled rockets, shells and similar apparatus. The method of depositing the coating shown in Fig. 42 has been described in connection with Fig. 25. It is an example of a holder for an electron multiplier where the usual potential dropping resistor from

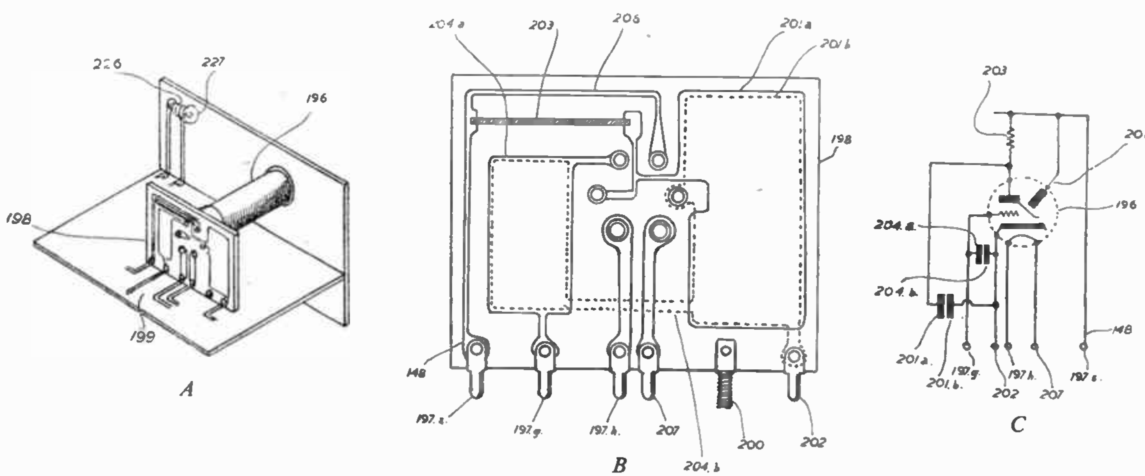


Fig. 40.—Use of right-angled assembly: (A) Plug-in type sub-assembly. (B) Plug-in panel. (C) Circuit of A and B.

Lastly, Figs. 41 and 42 (p. 27) show the most economical methods of making a valve holder as part of an interrelated circuit network. Fig. 41 electrode to electrode are not independent elements. They are all deposited together as a ring 213 of a high resistance material upon which the metal contacts are superimposed. At the same time other conductor paths are deposited, e.g. 215 lead to other parts of the apparatus.

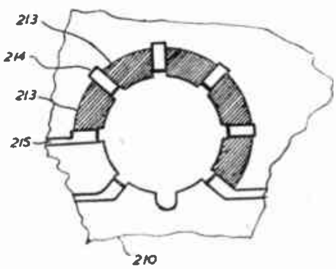


Fig. 42.—Method of incorporating resistor chain into the moulding such as is used with electron multipliers.

This is another case where the resistive material can be incorporated in the moulding process as the filler of the plastic material which is squeezed into position in the mould.

It will be seen from the foregoing that this system provides means whereby electrical circuits and their interrelated components can be constructed in a practical manner as integral parts of a plate or support. The number of plates or supports carrying circuits or parts of circuits can be mechanically and electrically connected together to form a complete apparatus. When essential plug-in components have been incorporated, the apparatus can then be introduced into the containing case or cabinet in such a way as to ensure that electrical connection is established to the source of operating current.

Section 4. METHOD OF PRODUCTION

4.1. Adoption of this design conception for the construction of electrical and radio equipment results in apparatus being developed in a form that lends itself to the highest degree of mechanization in manufacturing methods.

When the circuit to be reproduced has been finalized and laid out in accordance with the principles already described, production proceeds on the following lines.

4.2. Insulated plates are moulded to the required design with grooves and depressions on both sides.

If after moulding the plates are stored or transported, the surface moisture is driven off the surface of the plates by irradiation with infra-red rays before passing on to the next operation.

The smooth surfaces of the insulated plate are now roughened, particularly in the grooves and depressions, by blasting with abrasive grit to ensure that the metal to be sprayed will adhere firmly to the plate.

The plates are then cleaned to remove all traces of grit.

4.3. Then follow stages of metallization by metal spray pistols on both sides of the plate simultaneously. The number of these stages depends on the thickness of metal required in the final product. The groups of metallizing pistols are all electronically-controlled to ensure uniformity, safety, economy and reliability.

4.4. Both sides of the insulated plate are subjected to high-speed face milling operations to remove the metal coating in between the indentations, and to reveal the desired composite metal-plastic plate with metal in the grooves forming a network of conductors, inductors and terminations, and, in the deep recesses on either side of the thin webs of insulating material, forming the capacitors. All are interconnected *ab ovo* without resort to manual operations.

4.5. The plates are now automatically tested whilst still on the conveyor, before passing to the following operations. If the tests reject more than one plate in succession, the previous operation machines are adjusted or halted, depending on the degree of trouble revealed in the tests. The following operations on plates which have already passed this test point are not halted. (This is a novel and fundamental improvement in conveyor production technique and removes the objection to production machinery being linked together on the ground that interdependence of machines causes increased scrap.)

4.6. The plates having passed the tests, pass to graphite spraying operations through stencils which are automatically applied and indexed after having been automatically cleaned and dried. (The cleaning process ensures accuracy of resistor contour and economy in the resistor material which is recovered in the system.) The automatic timing of the spraying operation ensures the accuracy of the resistor values and is controlled by automatic resistance testing equipment further along the conveyor. The graphite deposits are also burnished to consolidate the coatings and so ensure resistance stability.

4.7. The plates travel into successive machines which first automatically remove unwanted material, plastic, metal or graphite, from holes, slots, etc. Secondly, metal sockets are automatically inserted, and these form the terminations for components (valves, electrolytic capacitors, loudspeakers and the like) which, obviously, cannot be made by the process. Thirdly, these sockets are clinched and fixed permanently in position by a special combined riveting, welding and soldering operation.

4.8. Now follows a further electrical testing operation with rejection of defectives and automatic backward control of the earlier operations to avoid repeat rejections.

4.9. At this stage, plates are subjected to overload electrical and thermal ageing processes whilst still in the conveyor system. This process is of predetermined duration to suit the product and to increase its stability and reliability. The plates are then sprayed with lacquer to seal them, drying off by their own heat.

4.10. The conveyed products now emerge from the enclosed machinery on to moving belts of a more conventional nature, using some manual aid, though largely automatized. The movable vanes of semi-variable capacitors are inserted by hand, and automatically fixed by the novel combined, clinching, welding, soldering operation. The valves and other prefabricated components are then plugged in and panels assembled. These are again automatically aged and tested and the various plates made by interconnected branch conveyor processes are assembled, and automatically re-tested.

4.11. One of the branch conveyor machines also produces the metal inserts, such as mains plug and switch parts, mains resistor terminations and tapping by a novel automatic die-casting system into pre-moulded recesses and grooves in a specially designed plastic cabinet, moulded without conventional metal inserts.

4.12. These metal inserts and strips are then interconnected automatically by a graphite spraying and burnishing machine which produces the mains voltage dropping resistor within predetermined parts of the cabinet.

4.13. The cabinet and its electrical parts then

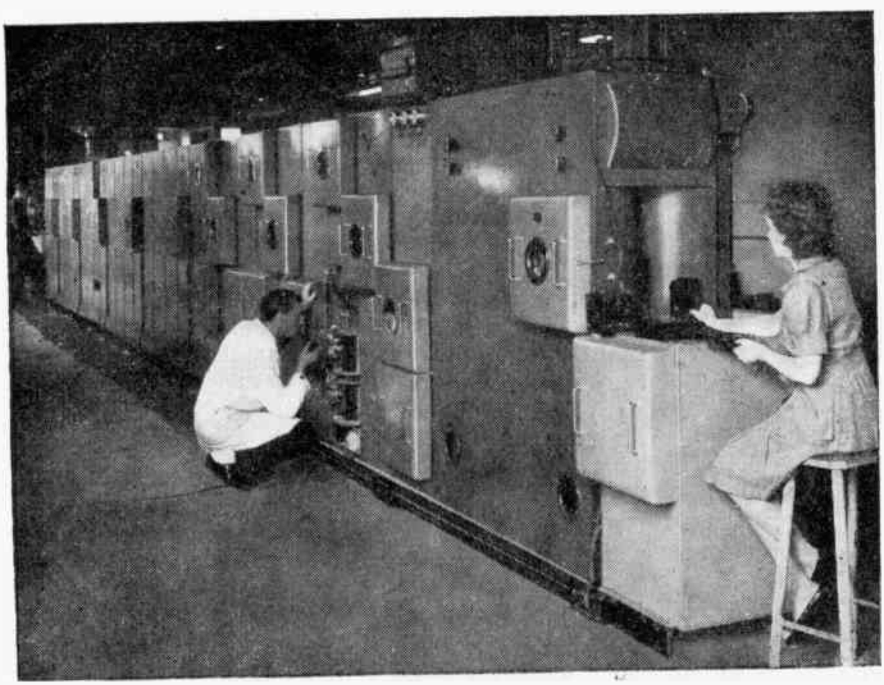


Fig. 43.—Type "A" conveyor, which incorporates the complete electronic circuit-making equipment. It embodies grit blasting, metallizing, face milling, lacquering an circuit testing units.

undergo electrical and thermal ageing for a predetermined time with subsequent automatic test before passing to the human assemblers.

4.14. The assembly of plates is automatically tested before and after insertion into the cabinet; then the completed set is tested on radio signals. It now passes through to an automatic packing and sealing equipment which is also part of the total production line, leading by conveyor to the outward stores.

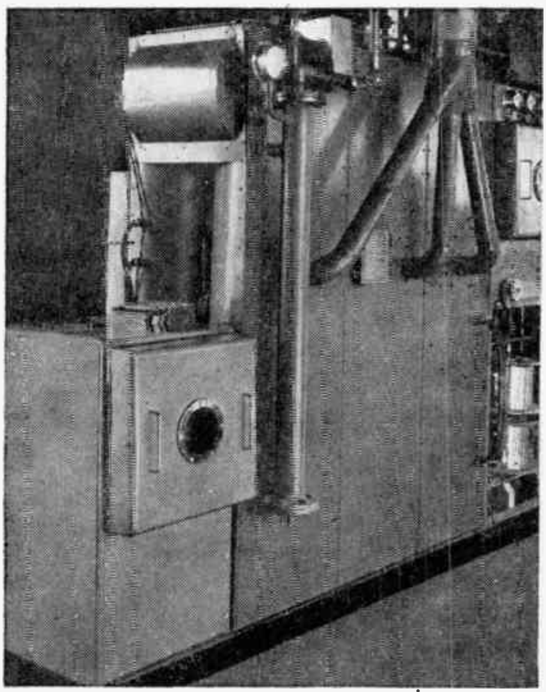


Fig. 44.—A close view of the electronically controlled grit blasting unit, incorporated in the conveyor shown in Fig. 43. *The conveyor speed is about* 20 *in. per minute, capable of a maximum flow of* 180 *seven-inch panels per hour.*

Section 5. PRODUCTION EQUIPMENT

5.1. The equipment has been designed on a unit construction system. The combination of fully automatic, electronically controlled machines in a conveyor line is determined by the interrelated circuit elements to be fabricated.

For example, a circuit embodying inductors and capacitors is processed in a type " A " conveyor comprising the following machine groups in this sequence :—

a. Grit blasting.
b. Metallizing.
c. Face milling.
d. Lacquering.
e. Circuit testing.

A type " B " conveyor can produce a circuit containing resistors, capacitors, potentiometer tracks and valveholders and has additional machines to those in type " A " conveyor arranged in the following order :—

a. Grit blasting.
b. Metallizing.
c. Face milling.
d. Graphite spraying.
e. Socket inserting.
f. Lacquering.
g. Circuit testing.

5.2. In order to appreciate more easily the sequence of the various operations and the manner in which they are achieved, the progress of a moulded panel through type " A " conveyor will be described.

The unit construction system will be noted in Fig. 43 (p. 28), which is a view of conveyor type " A " of the electronic circuit making equipment (E.C.M.E.).

Preformed moulded insulated plates are loaded into the guide rails of the conveyor. Photoelectrically the presence of the plate is registered by the master electronic control unit (housed in the small cubicle in the foreground) and the plates are automatically fed into the automatic grit blast machine, the entry of which can be more clearly seen in Fig. 44.

It is necessary that the smooth surfaces of the moulded plates, particularly the walls of the grooves and depressions, should be well and evenly roughened in order that the metal to be sprayed will adhere firmly.

This operation is carried out by forcing a fine abrasive agent through tungsten-carbide nozzles. The nozzles have been arranged, as a result of experiments, in such a way that no part of the plate surface is neglected. As the plate passes through the machine, the nozzle units are rocked up and down to obtain the desired result.

Like all operations which take place in the E.C.M.E., the grit-blast machine is electronically controlled and does not commence work until a plate arrives for blasting. This avoids excessive wear of the nozzles. The operation is dependent also on the presence of abrasive agent, and the correct feed of compressed air. The failure of supplies, or should the conditions be incorrect to produce a satisfactory result, the machine is automatically shut down at once and the alarm is given.

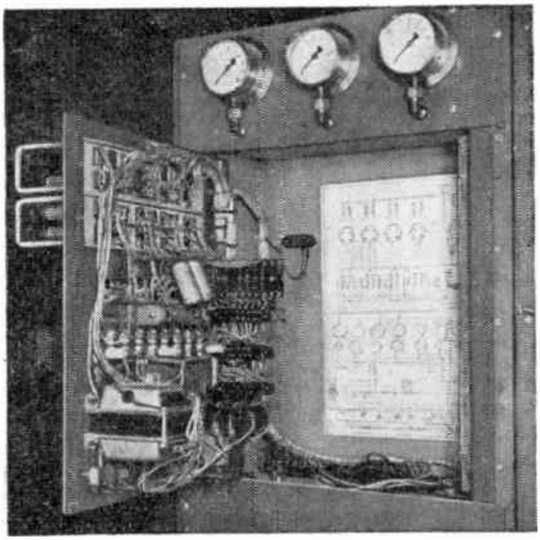


Fig. 45.—Close view of electronic control unit. It controls admission and ignition of ethane, propane and oxygen, zinc wire feed and returns equipment to safety condition when operation is completed, or should any part of the equipment fail.

A photo-electric device checks each plate for roughness on ejection from the grit-blasting machine before passing on to the next process.

Roughened plates leave the rubber conveyor which carried them through the grit blasting machine and they are automatically picked up by the chain conveyor which propels them through the metallizing group.

5.3. Metallizing Machine Group

Here again, the whole process is completely automatic and is controlled throughout by the electronic control unit (Fig. 45). The metal spray machines are of particular interest and represent an advance on standard practice in spraying technique. Each machine has eight nozzles arranged four-a-side to allow simultaneous spraying of both sides of the plate (Figs. 46 and 47).

Spraying takes place only when there is a plate in position for processing. The machine is started up, closed down or reverts to safety conditions in case of failure in any part of the system by the electronic control unit, and also if the control unit fails.

Zinc wire on reels can be seen in the lower cubicles, and this is fed to the metallization guns over a system of pulleys which send electrical impulses, when rotating, to the electronic control unit shown in the top left-hand cubicle, thus checking both the presence of wire and the correct feeding conditions.

Figure 47 shows more clearly one four-nozzle metallizing mechanism together with its associated electronic control unit.

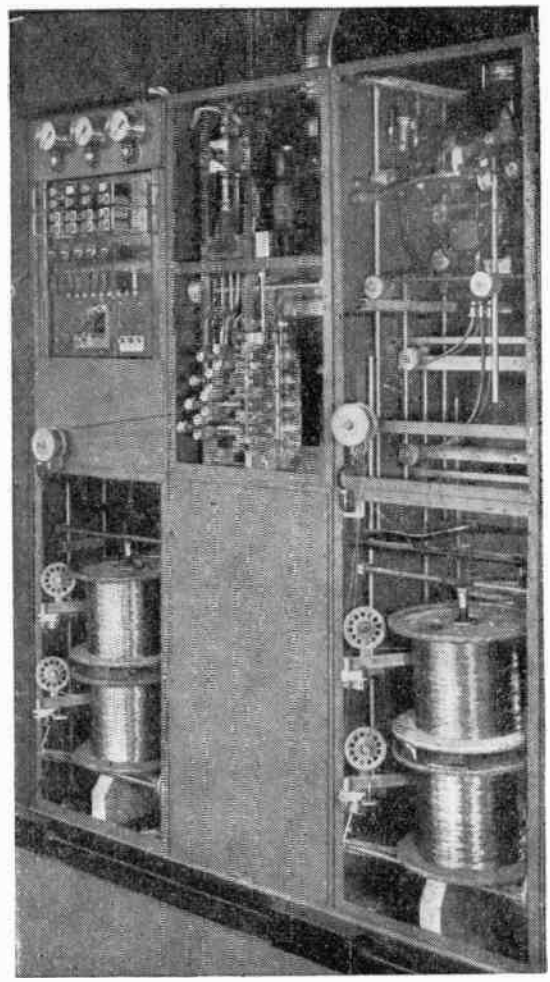


Fig. 46.—Showing interior of eight-gun metal spraying machine. The spray-guns are arranged four on each side, and one set is shown in centre cubicle. Like all other units in the equipment, this is electronically controlled.

The eight nozzles, of which four can be seen in this picture, are mounted on a rocking mechanism driven at a speed that ensures even distribution of metal on the plate during its progress through the cubicle.

The arrival of a plate on the conveyor is perceived by the control unit which starts the process timing cycle and regulates the admission and ignition, in the correct sequence, of ethane, propane and oxygen. It also starts and controls the

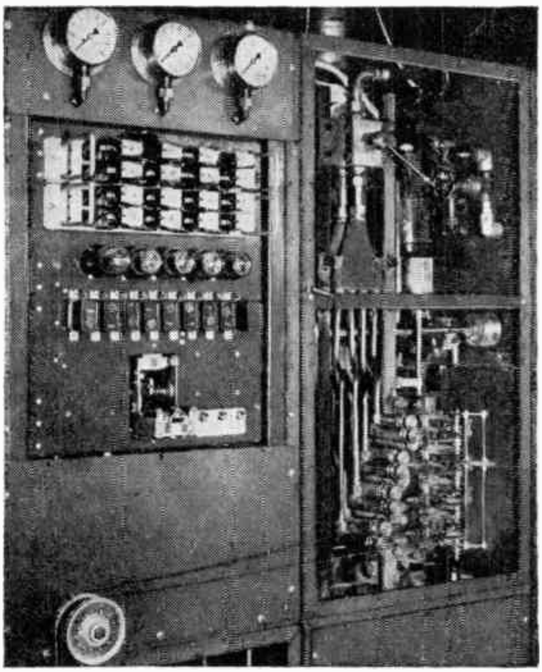


Fig. 47.—A closer view of automatic metal spraying unit showing electronic control unit.

supply of zinc wire into the melting flame, and admits compressed air for atomizing and spraying the molten metal.

These supplies are shut down when the flow of plates ceases or, in the case of failure of any part of the metallizing system, including that of the electronic control unit itself, the machine reverts to a safety condition.

When a continuous row of plates pass through the metallizing machine, the timing circuit of the control unit perceives each plate in turn and extends the operating time until the last plate has been processed before reverting to quiescence.

This is an example of an electronic device carrying out an operation which would be most dangerous to attempt by hand, were it possible manually to control eight metallizing pistols simultaneously.

Since this control is applied in a positive sense, that is to say, all conditions must be correct before the machine will function at all, it has been possible to render this process completely safe despite the dangerous nature of the gases employed.

At the same time, the greatest economy in power and material is assured since the machine operates only when there is work to be done.

Metallized plates coated with metal by one or more such machines in sequence to the required thickness are then passed over by the chain conveyor to rubber rollers which feed them over face plates of the face milling machine group.

5.4. Face Milling Machine Group

The insulated plates, at this stage completely coated with metal, are fed through a battery of face milling machines illustrated by Fig. 48.

This process is entirely electronically controlled and is started by the presence of a plate. Precautions are taken automatically that the cutting heads attain their operating speeds before the metallized

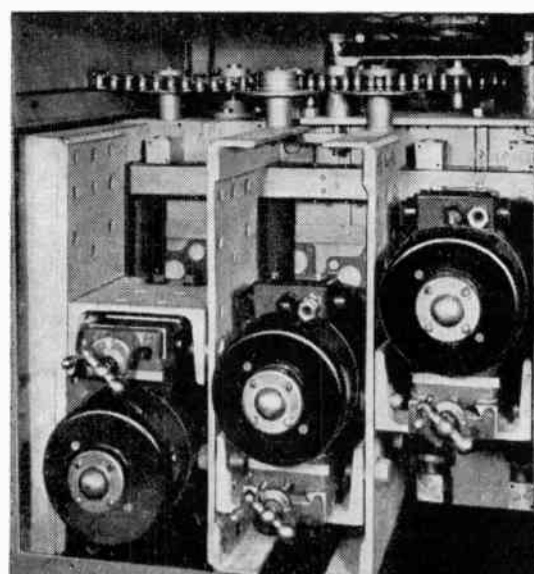


Fig. 48.—Automatic face milling heads. Panels being processed can be seen protruding just above heads 1 and 2.

insulated plate is fed·in by the rubber rollers to avoid forcing work past a dead tool. In this way, scrap is reduced, and economy in tool life is ensured.

Each face milling machine has three electrically driven milling heads, each mounted on independent slides capable of adjustment to the finest limits.

It is noteworthy that during this operation, carried out at 3,000 ft./min. tool speeds, the insulated plate is unclamped and is fed past rotating diamond tipped tools by rubber rollers. These revolving rollers are spring loaded to hold the plate flat on the face plate between guides.

In this manner metal is removed in successive layers from each face of the plate until the insulated material separating the grooves and depressions is reached. This leaves the interconnected circuit in the grooves complete as designed and is finished by polishing.

The plate continues along the conveyor for automatic socket insertion, followed by lacquering and automatic electrical check test where the completed circuit is rapidly subjected to exhaustive point-to-point comparison against a standard.

Plates which do not conform to the predetermined limits are rejected from the conveyor line, but satisfactory ones continue their journey for assembly.

Conclusion

In addition to the more obvious advantages to be gained by adopting this principle of growing complete interrelated and interconnected circuit elements as a means of achieving much larger outputs with minimum manpower, this conception

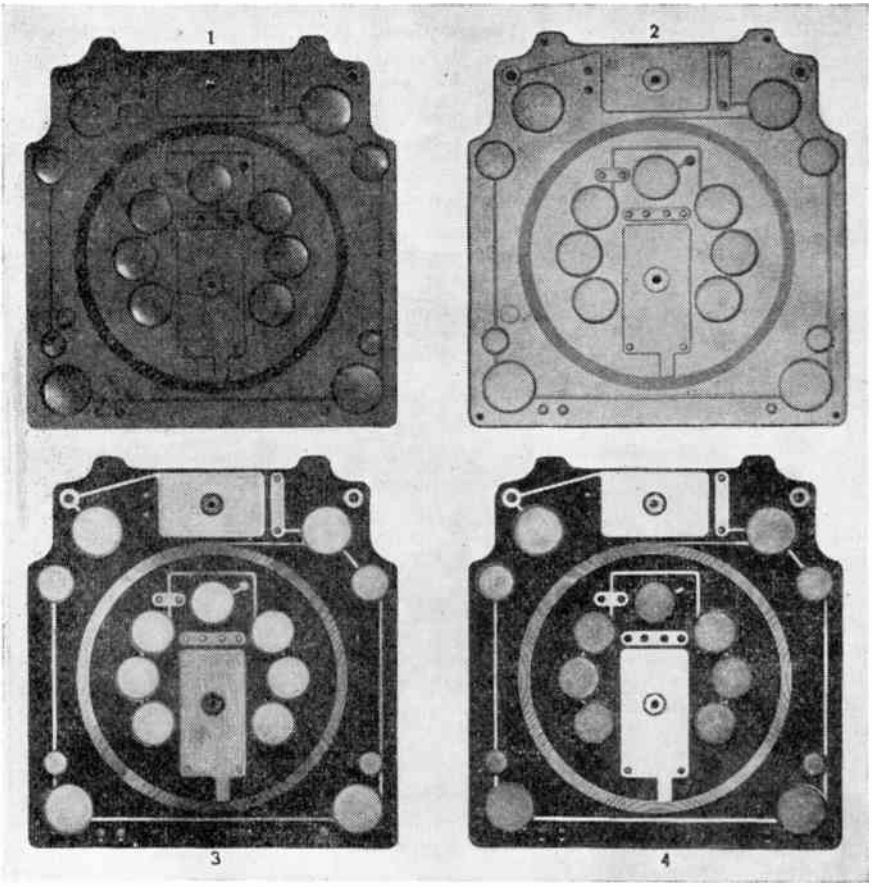


Fig. 49.—Showing panels at various stages of processing.

(1) *Virgin moulded panel.*

(2) *Panel fully metallized.*

(3) *Panel after face-milling operation—circuit is revealed.*

(4) *After panel has been lacquered.*

of design and manufacturing possesses many further attractions not readily appreciated.

1. For example, the number of elements on the insulated plate does not affect its cost. Components can be added or eliminated without involving costing difficulties. The tool producing the moulded plate is suitably modified or the mask responsible for the resistor network is altered and there the matter ends.

2. Wiring mistakes just cannot happen in this system, and inspection problems cease to be a costly item.

3. By virtue of the fact that the results of all automatic tests carried out on the plates during processing control preceding operations, a very high degree of uniformity is assured.

4. The rate of production is controlled and is capable of being instantly adjusted to requirements by simply regulating the flow of plates into the plant.

5. Separate fabrication or purchasing of all but a few components is eliminated, and this eases purchasing department and stock problems. The danger of being left with large quantities of redundant or obsolete components is reduced, since only a very few items cannot be catered for by the E.C.M.E.

6. Production can continue at a preset rate with complete uniformity all around the clock, and unaffected by changes of shift.

7. Electronic control assures complete safety and, at the same time, maintains maximum economy in consumption of material and power.

8. Radio circuits contained in plastic panels can be completely protected for tropical conditions.

9. Large quantity production could be achieved in a much shorter time than by existing methods.

10. The cost of apparatus is reduced, permitting the scrapping of units which become unserviceable, instead of maintaining large highly-skilled maintenance staffs in the field to repair complex equipment.

11. Production is achieved with minimum labour and greater output per worker.

12. Equipment made by this process is more robust and much lighter in weight, thus easing shipping problems and increasing pay-load.

13. In many cases it will be unnecessary to pressurize airborne apparatus for high altitude working as at present.

This design conception has been confined, so far, to simple circuits and at present no data are available on the application of these principles to more ambitious apparatus.

However, it is certain that simple receivers such as that described can satisfy the large demand which exists for inexpensive radio equipment which cannot be exploited by orthodox construction methods.

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Acknowledgments

I wish to acknowledge the encouragement, help and advice given during the ten years of this development work to my good friends, A. A. Thornton and G. D. Clifford, also to R. E. Blaise for the editorial help in connection with this paper.

TRANSFERS AND ELECTIONS TO MEMBERSHIP

The following elections and transfers were recommended by the Membership Committee at their meetings of November 26th, 1946, December 17th, 1946, January 28th, 1947, February 13th, 1947, and February 25th, 1947.

Transferred from Associate Member to Full Member

HAMBURGER, Gerhart Lother London
NIXON, William Geoffrey John Hackbridge, Surrey
SPREADBURY, Edwin Arthur William North Harrow

Transferred from Associate to Associate Member

AKESTER, Henry William Hull
JONES, David St. John, M.B.E. London, S.W.1

Transferred from Graduate to Associate Member

WOODS, Alfred Walter Ray Cape Town

Transferred from Student to Associate

BROWN, Albert Geoffrey West Bridgford
CARVILLE, William Willett London, N.17
HODGKINSON, John Thomas Kenya
HYDE, Norman George Rugby
HUNT, George Ernest Alton, Hants.
MIDDLETON, Eric John Johannesburg
OSBORNE, Basil Whitworth Bournemouth
SAUNDERS, Eric George Thorp Walsall
STULAND, Tor Sunnordland, Norway
WOLFENDALE, Frederic Caleb Hanwell
WULKEN, Alfred Haifa, Palestine

Transferred from Student to Graduate

KRAICER, Alec London, N.W.3
O'NEILL, Daniel Dublin
SUGDEN, Stuart Morton Liverpool

Elected to Full Member

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WRIGHT, George Thomas Blackpool

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HAIGH, Kenneth Richardson Liverpool

(Continued on p. 35).

Elected to Associate (contd.)

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RADIO WAVES AND THE IONOSPHERE*

by

Professor G. W. O. Howe, D.Sc.

A Paper read before the Scottish Section of the Institution on October 10*th*, 1946, *and before the London Section on November* 21*st*, 1946.

When asked in 1944 to give an address on the principles and theory of this subject from a historical point of view, I pointed out that some outstanding achievements in the early days of wireless telegraphy were accomplished in spite of principles and theory. Many of the most spectacular advances had been made, not along lines indicated by a study of principles and theory, but rather contrary to such indications, and the success achieved then led to a revision of the principles and theory.

As I said on that occasion, if in 1900 Marconi had consulted a panel of the leading scientists as to the feasibility of sending wireless signals across the Atlantic, it is doubtful whether he would have made his classic experiment. They would have pointed out to him that the electromagnetic waves employed were of the same nature as light, and that between this country and America there was a mountain of sea water over a hundred miles high. Principles and theory were all against him, but fortunately he made the experiment and gave those versed in the principles and theory the task of adjusting them to explain the facts, a task which was commenced soon after by Heaviside and Kennelly in 1902, and which has been pursued ever since by many scientists with wonderful results.

In the 'eighties, Balfour Stewart had suggested the existence of a conducting layer in the upper atmosphere, the currents in which might be the cause of fluctuations in terrestrial magnetism, but until the discovery of the electron and ionisation, such a suggestion could only have been a vague idea. In 1908 Professor Fleming mentioned Heaviside's suggestion, but said that " no data are at present available to give support to the conclusion." He even put forward an alternative suggestion that the transmission was due to the earth connection of the transmitting and receiving aerials. It was not until 1912 that Dr. Eccles gave the first clue as to the real nature of the mechanism by which the electromagnetic waves are bent around the earth and, except that he ascribed the action to the positive gaseous ions and not to the negative electrons, his explanation has been amply justified by subsequent research. Owing to the first world war the matter seems to have made little progress until 1924 when Larmor published a paper on the subject in the *Philosophical Magazine*, in which the negative electrons replaced the positive gaseous ions. In 1925, in a paper published by Smith Rose and Barfield, it was stated that " adequate experimental evidence of the existence of the Heaviside layer is still lacking." But things were moving more rapidly, for in the following month Appleton and Barnett showed that the refracted waves were all elliptically polarized, due to the magnetic field of the earth, and calculated that there must be at least 100,000 electrons per cubic centimetre in the ionised layer. In the following year they showed that the height of the layer increased during the night and then decreased rapidly about sunrise.

In 1931 Appleton showed that there was a second layer at a much greater height than the first one and he called them the E and F layers, although they are sometimes referred to as the Heaviside and the Appleton layers. There are indications that the upper layer is sometimes further divided into two, known as the F_1 and F_2 layers.

After this historical introduction we must turn our attention to the mechanism whereby the radio waves which enter the ionosphere are caused to return to the earth.

A medium in which the velocity of wave propagation varies with the frequency is called a *dispersive medium.* It is because glass is such a medium that a glass prism treats every colour differently. The ionosphere is such a medium.

The gas atoms which constitute the upper atmosphere are to some extent ionised, that is, split up into a positive nucleus and a free electron ; it is because they have lost the negative electron that some of the gas atoms are positive. There will also be a number of neutral gas atoms which have not lost an electron. We now know that it

* *U.D.C. No.* 621.396.11 : 551.510.535

is due to the free electrons that the ionosphere has the peculiar properties which play such an important part in radio transmission. When an electric wave passes through the ionosphere, the free electrons are acted on by the electric field, and caused to oscillate. It is very important to realise that when the force acting on the electron is at a maximum in one direction the electron is at the end of its swing, that is, has its maximum displacement in the opposite direction because it is then that its acceleration in the direction of the force is at a maximum. In a vacuum we picture the electric field producing an electric displacement —the Maxwellian displacement—in the same direction as the force, hence the effect of the free electrons is opposed to that of the displacement current and reduces the effective dielectric constant of the space. This is exactly the opposite to what happens in a dielectric such as ebonite or mica where the electrons are not free, but form a part of the atom and are displaced by any applied electric field against the forces which hold the atom together. In this case the displacement of the electron would be in the direction of the force acting upon it.

In the ionosphere it is easy to prove that instead of unity the dielectric constant will be $1-\alpha N/f^2$ where f is the frequency, N the number of free electrons per cubic centimetre, and $\alpha = q^2/\pi m$. The charge q of an electron is $4{\cdot}803\times10^{-10}$ electrostatic unit and its mass m, $9{\cdot}11\times10^{-28}$ gramme, so that $\alpha = 8{\cdot}1\times10^{7}$.

Since the velocity of an electromagnetic wave is inversely proportional to the square root of the dielectric constant κ, this reduction of κ means that the velocity must be greater in the ionosphere than in a perfect vacuum.

At first sight this appears to be contrary to the theory of relativity, but the apparent discrepancy was explained by Sommerfeld forty years ago. The velocity thus calculated is that of a certain phase of a wave of constant amplitude and with neither beginning nor end, and therefore with no means of measuring its velocity. Such concepts can travel at velocities greater than that of light, in fact, at a multiple of it, without violating the laws of relativity. If one were to watch from a boat a sea wave breaking against a long sea wall, and note especially the moment when the crest of the wave struck the wall at different points along the front, the result would depend on the angle between the wave and the sea wall. If the wave were exactly parallel to the sea wall the crest would strike the wall at the same moment at every point along the front, but if there were a very small angle between them, the intersection of wavecrest and wall would sweep along the sea wall with a great velocity which would approach infinity as the angle became smaller and smaller. What is it that moves with this great velocity? Merely the locus of a certain phase relationship. When we speak of the phase velocity of a wave we mean the velocity with which a given crest or trough travels. In a vacuum we denote this phase velocity by c, in any other medium by v, and from what we have just said it will be seen that in an ionised medium $v = c/\sqrt{(1-\alpha N/f^2)}$. To measure the velocity of the wave, however, it is necessary to impress upon it some modification that can be recognised, i.e. to modulate it in some way, but when the experiment is made it is found that the signal or modification does not travel at the same speed as the crest or trough of the wave. In the case of the ionised medium, instead of confirming a velocity greater than that of light in vacuum, it gives a velocity smaller than that in a vacuum. Probably the simplest way of approaching this problem is to imagine a transmitter sending out simultaneously two waves of slightly different frequencies but of equal amplitude. At one moment at any point the two waves will be in phase, giving therefore a double amplitude, whereas a moment later they will be 180° out of phase and neutralising each other. This is

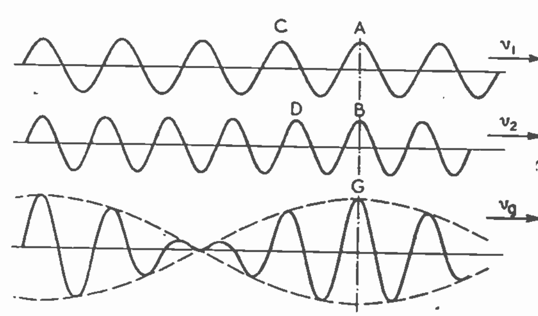

Fig. 1.

illustrated in Fig. 1 which shows two waves, the upper one with a wavelength λ_1 = AC, moving with a phase velocity v_1 and the lower one with a wavelength λ_2 = BD, moving with a phase velocity v_2. At one point at the given moment the crests A and B coincide and give a resultant crest G. On either side of G the waves are out of phase and the resultant amplitude is smaller, falling to zero where the two waves are in opposition. It is seen that the resultant wave consists of a series of pulses or groups of waves and the velocity with which they move is called the group velocity. A study of the propagation of these groups is essential to an understanding of what transpires in wave propagation through the ionosphere.

The above formula for v shows that if f is very big $\alpha N/f^2$ will be very small indeed and v will approximate to c, but as f gets smaller, and therefore λ bigger, v becomes greater than c. Hence, the longer the wavelength the faster the wave travels, and the upper wave in Fig. 1 will consequently gradually overtake the lower wave until C and D coincide, and with them the mid point G of the group. Hence G does not keep up with either of the waves but gradually falls behind. The time required for C to catch up to D will be $(\lambda_1 - \lambda_2)/(v_1 - v_2)$ and in this time the upper wave will have travelled a distance $v_1 (\lambda_1 - \lambda_2)/(v_1 - v_2)$ but the point G will have travelled a distance AC less than this, viz: $v_1 (\lambda_1 - \lambda_2)/(v_1 - v_2) - \lambda_1$. This is the distance travelled by the group in the time $(\lambda_1 - \lambda_2)/(v_1 - v_2)$ and for the group velocity we have

$$v_g = \frac{v_1 (\lambda_1 - \lambda_2) / (v_1 - v_2) - \lambda_1}{(\lambda_1 - \lambda_2) / (v_1 - v_2)}$$
$$= v_1 - \lambda_1 (v_1 - v_2) / (\lambda_1 - \lambda_2)$$

Similarly, by considering the second wave we get

$$v_g = v_2 - \lambda_2 (v_1 - v_2) / (\lambda_1 - \lambda_2)$$

Assuming that $v_1 - v_2$ and $\lambda_1 - \lambda_2$ are relatively small and that their ratio may be taken as constant over the range involved, we can therefore write $v_g = v - \lambda dv/d\lambda$.

The above formulae could also be written

$$v_g = \frac{v_2\lambda_1 - v_1\lambda_2}{\lambda_1 - \lambda_2} = \frac{\dfrac{v_2}{\lambda_2} - \dfrac{v_1}{\lambda_1}}{\dfrac{1}{\lambda_2} - \dfrac{1}{\lambda_1}}$$
$$= \frac{f_2 - f_1}{1/\lambda_2 - 1/\lambda_1} = \frac{\omega_2 - \omega_1}{\beta_2 - \beta_1} = \frac{d\omega}{d\beta}$$

Where β has been put for $2\pi/\lambda$.

This is a well known result and it is surprisingly simple. We see that the group velocity depends only on the extent to which the wave-length, or rather, its reciprocal, changes with small changes of frequency.

From the formula

$$v = c/\sqrt{(1 - \alpha N/f^2)} \quad \ldots\ldots\ldots\ldots\ldots (A)$$

we have

$$1/\lambda = f/v = f\sqrt{(1 - \alpha N/f^2)}/c$$

and therefore

$$\frac{d(1/\lambda)}{df} = \frac{1}{c} \cdot \frac{1}{\sqrt{(1 - \alpha N/f^2)}}$$

from which

$$v_g = \frac{df}{d(1/\lambda)} = c\sqrt{(1 - \alpha N/f^2)} \quad \ldots\ldots (B)$$

On comparing the two formulae A and B it is seen that $v \times v_g = c^2$, that is to say, the constant velocity c in a vacuum is the geometric mean of the phase and group velocities in the ionised medium, and the group velocity can be found at once from the phase velocity, since $v_g = c^2/v$.

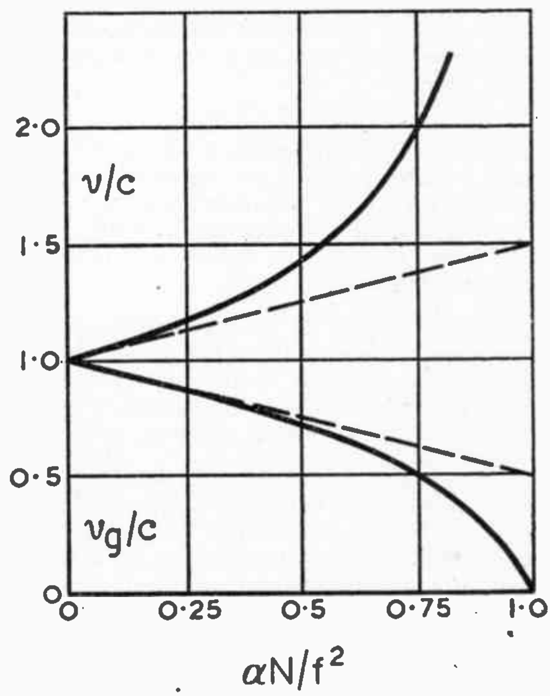

Fig. 2.

Fig. 2 shows how the ratios v/c and v_g/c vary with $\alpha N/f^2$. When $\alpha N/f^2$ is small $\sqrt{(1 - \alpha N/f^2)}$ approximates to $1 - \alpha N/2f^2$ and both v/c and

v_g/c vary linearly; when $\alpha N/f^2 = 1$, $v_g = 0$ and v becomes infinitely great.

To obtain a clear picture of what happens when a series of pulses as shown in Fig. 1 penetrates into the ionosphere I think it advisable to take a numerical example, and I will take the same example as I used in *The Wireless Engineer* of December, 1943. I assume that the transmission is vertically upwards as is actually the case in many experiments, and that the pulses are due to

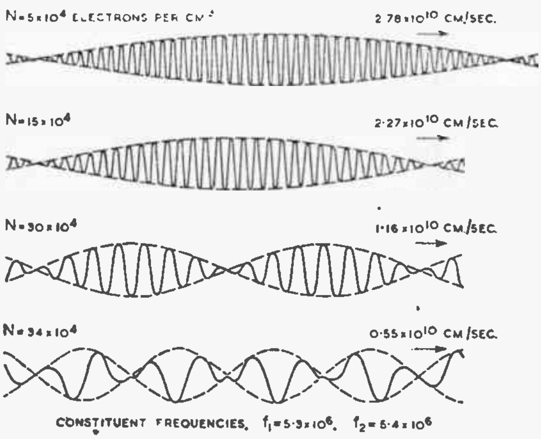

Fig. 3.

the interaction of two sustained waves, one with a frequency of 5·3 Mc/s and the other of 5·4 Mc/s.

If the electron density N is only 5×10^4 per cm.^{3}, $\alpha N/f_1^2 = 0{\cdot}1442$ and $\sqrt{(1 - \alpha N/f_1^2)} = 0{\cdot}9251$. This gives a phase velocity v of $3{\cdot}243 \times 10^{10}$ cm./sec. and wave-length λ of 6,119 cm. Similarly for the other wave, $\alpha N/f_2^2 = 0{\cdot}1389$, $\sqrt{(1 - \alpha N/f_2^2)} = 0{\cdot}928$, $v_2 = 3{\cdot}233 \times 10^{10}$ and $\lambda_2 = 5{,}987$ cm.

The group velocity $v_g = 3 \times 10^{10} \times 0{\cdot}9265 = 2{\cdot}78 \times 10^{10}$ cm./sec. The length of a group or pulse can be seen from Fig. 1 to extend from a point where the two waves are in phase to the next point at which this occurs, which must be where $n\lambda_1 = (n + 1)\lambda_2$. This gives $n = 45{\cdot}3$, so that the length of the group is $45{\cdot}3 \times 6{,}119$ or $46{\cdot}3 \times 5{,}987$, i.e. 278,000 cm. Taking the mean of 45·3 and 46·3 the group is seen to contain 45·8 waves; such a group is represented at the top of Fig. 3 which, like the other figures, is reproduced from *The Wireless Engineer*.

Before entering the ionosphere the group contained between 53 and 54 waves. As it penetrates further into the ionosphere the electron density N increases, and with it the divergence between the phase and group velocities. The length of the waves increases while that of the pulses or groups decreases, with the result that each group contains fewer and fewer waves. This is shown in Fig. 3, which is drawn strictly to scale and shows in a striking manner the wonderful transformation that the pulses undergo as N increases from 5×10^4 to 34×10^4 electrons per cm.^{3}. A slight further increase to 35.35×10^4 makes $\alpha N/f^2 = 1$ and v_g falls to zero; the waves are then reflected and return to earth, going through all the transformations of Fig. 3 in the reverse order. If the maximum value of N in the layer were less than 35.35×10^4, the wave which we have been considering would pass through it without reflection; for reflection to occur $\alpha N/f^2$ must reach the value 1, i.e. $N = f^2/\alpha$; this shows how the electron density necessary for reflection depends on the frequency. If the frequency is doubled, four times the density is necessary for reflection. If instead of being sent up vertically the wave is sent up at an angle θ to the vertical, it will be refracted on entering the ionosphere and its angle to the vertical will increase with increasing N. When a wave passes from a medium of dielectric constant κ_1 into another of dielectric constant κ_2 then

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \sqrt{\frac{\kappa_2}{\kappa_1}}$$

i.e., the sines of the angles are proportional to the phase velocities. In our case $\kappa_1 = 1$ and $\kappa_2 = 1 - \alpha N/f^2$. If θ_2 becomes 90° the wave is moving horizontally, that is, it has reached the top of its path and will then bend downwards and return to the earth. Since $\sin 90° = 1$, for this to occur $\sin\theta_1$, must equal $\sqrt{\kappa_2}$, i.e. $\sqrt{(1-\alpha N/f^2)}$. For a wave of a given frequency f entering the ionosphere at a given angle θ to the vertical, we can therefore calculate the electron density N necessary to deflect the wave downwards and cause it to return to the earth. For long distance transmission the wave should obviously be sent out horizontally, so as to reach the ionosphere as far away as possible. If we assume that it enters the ionosphere at an angle of 80° to the vertical, and if we know from published data the maximum value of N at that place and time, we can calculate the highest frequency that will be returned to earth; any wave at a higher frequency will penetrate the layer and go off into space. This is known as the M.U.F.—the maximum usable frequency, and its determination in advance is known as ionospheric forecasting. It may be asked, why not use lower frequencies for which there would be no doubt about the reflection? The answer to this question involves an important phenomenon which we have so far neglected, viz., the loss of energy and consequent attenuation of the wave due to collisions between the oscillating electrons and the gas atoms. As we have seen, the amplitude of the electron oscillations is inversely proportional to the square of the frequency. Hence, if the frequency is halved, the electrons oscillate over four times the length of path, with twice the average velocity and four times the kinetic energy, or would do so, were it not for collisions with the atoms, the probability of which is increased owing to the longer path. It can be shown that the attenuation of the wave expressed in decibels is inversely proportional to the square of the frequency. Hence, to reduce the attenuation to a minimum and obtain optimum results in long-distance transmission, one must use the highest frequency that the ionosphere is capable of reflecting. One must naturally allow a certain factor of safety and employ a frequency somewhat below the critical value.

There are now over fifty stations in different parts of the world making regular observations of ionospheric reflection and sending the results to central organisations where the data are correlated and made generally available for forecasting purposes.

Up to this point we have made no reference to the fact that the earth's magnetic field extends into the ionosphere and has an appreciable effect on the movement of the electrons. An electron in motion is equivalent to an electric current and therefore experiences a mechanical force in a direction at right angles to the motion and to the direction of the field. To simplify the problem we shall assume that the magnetic field is in the direction of wave propagation; if it is in any other direction we shall only concern ourselves with the component in the direction of wave propagation. It simplifies the problem to regard the plane polarized wave as the resultant of two circularly polarized waves, that is, to resolve the alternating field $\hat{\varepsilon}$ into two fields of constant magnitude $\hat{\varepsilon}/_2$ rotating in opposite directions. The effects of these two fields can be studied separately and the results then combined. Each rotating field will exert a constant but rotating force $q\,\hat{\varepsilon}/_2$ on each electron. An electron rotating in the plane normal to the field will experience a force due to its movement in the magnetic field; this force will be radially inwards or outwards depending on the direction of rotation. If r is the radius of its path and ω the angular velocity, its velocity will be ωr and the force on it $\omega r\,.\,q\,.\,H/3\cdot10^{10}$ dynes. The rotating electron is also subjected to a centrifugal

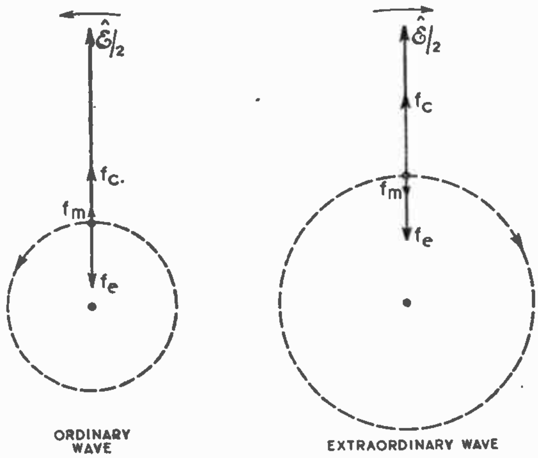

Fig. 4.

force $m\,\omega^2 r$ dynes acting radially outwards. In Fig. 4 we are supposed to be looking in the direction of transmission and therefore along the magnetic field H. As the charge of the electron is negative the force f_e acts in the opposite direction to $\hat{\varepsilon}/_2$. In the left-hand diagram the electron moving to the left is equivalent to a current element in the reverse direction, and an application of the left-hand rule shows that it will experience an outward force f_m, whereas in the right-hand diagram it will be in the opposite direction. Both f_c and f_m are proportional to the radius which adjusts itself until a stable condition is attained, that is, until $f_c = f_e - f_m$ for left-hand rotation, and $f_c = f_e + f_m$ for right-hand rotation. Substituting the values that we have found for these forces we obtain the equation

$$m\omega^2 r = -q\,\frac{\hat{\varepsilon}}{2} \pm \omega r q\ H/3\cdot10^{10}$$

It must be remembered that q is a negative quantity; the upper sign refers to the left-hand rotation, i.e., to the left-hand diagram.

If the electrons were not present the electric force would produce a displacement $\hat{\varepsilon}/8\pi$ in the direction of the electric force; from Fig. 4 we see that negative electrons are now displaced a distance r in the direction of the electric force, thus decreasing the resultant displacement to $\hat{\varepsilon}/8\pi + qNr$ where qN is the electronic charge per cubic centimetre involved in the displacement. Writing this formula for the resultant displacement

$\frac{\hat{\varepsilon}}{8\pi}\left(\frac{1+8\pi qNr}{\hat{\varepsilon}}\right)$ and substituting for $\hat{\varepsilon}$ from the above equation we obtain

$$\frac{\hat{\varepsilon}}{8\pi}\left(1-\frac{4\pi q^2 N}{\omega^2 m \mp \frac{\omega q H}{3\cdot 10^{10}}}\right)$$

$$\text{or}\quad \frac{\hat{\varepsilon}}{8\pi}\left(1-\frac{4\pi q^2 N/m}{\omega^2 \mp \frac{\omega q H}{3\cdot 10^{10} m}}\right)$$

The quantity in brackets is the effective dielectric constant κ which we may therefore write $\kappa = 1 - \frac{\omega_o^2}{\omega^2 \pm \omega\omega_m}$ where we have put ω_o^2 for $4\pi q^2 N/m$ and ω_m for $-qH/3\cdot 10^{10} m$. Substituting the known values of the charge q and the mass m of the electron we find that $\omega_o^2 = 3\cdot 18 \times 10^9 N$ and $\omega_m = 17\cdot 56 \times 10^6 H$. Since the phase velocity $v = c/\sqrt{\kappa}$ we can calculate it for any values of ω, N and H. We obtain two different values depending on whether we use the upper sign (left-hand rotation) or the lower sign (right-hand rotation). If ω_o and ω_m are small compared with ω, that is, for relatively small values of N and H, the right-hand rotation gives the smaller value of κ and therefore the higher phase velocity.

If in the right-hand diagram the force f_m due to the magnetic field becomes so large that it is equal to the centrifugal force f_c, no electric force will be necessary to maintain the rotation apart from losses. At this gyroscopic resonant frequency the radius will increase, and with it the velocity of the electrons and the losses due to their collisions with the positive ions and neutral atoms, until these losses are equal to the power which can be supplied from the electro-magnetic field of the wave. At this frequency the wave will be rapidly damped out. It is because of this peculiar behaviour that this right-handed wave is known as the extraordinary wave or ray. The phenomenally large attenuation occurs when $f_m = f_c$, that is, when $-\frac{\omega r q H}{3\cdot 10^{10}} = m\omega^2 r$ and therefore $\omega = \frac{-qH}{3\cdot 10^{10} m} = \omega_m$. Hence, ω_m in the above formula for κ is 2π times the magneto resonant frequency. If $H = 0$ and therefore $\omega_m = o$, we have $\kappa = 1 - \omega_0^2/\omega^2$; hence ω_o is the angular frequency at which reflection would occur in the absence of the magnetic field.

If H is so small, or the frequency so high, that ω_m is small compared with ω, and the electron density N so low that ω_o^2 is less than ω^2, the two values of κ will lie between 0 and 1 and the phase velocity of both waves will be finite. The right-handed wave (lower sign) will have the smaller κ and therefore the higher phase velocity, but also the greater damping on account of the higher velocity of its electrons and the consequent increased loss by collisions. The two advancing waves can be represented by two spirals, one right-handed and the other left-handed, representing the ends of the $\hat{\varepsilon}/_2$ vectors, but as the right-hand one has a greater pitch or wave-length, their resultant will gradually rotate, giving, in the absence of damping, a plane polarized wave with

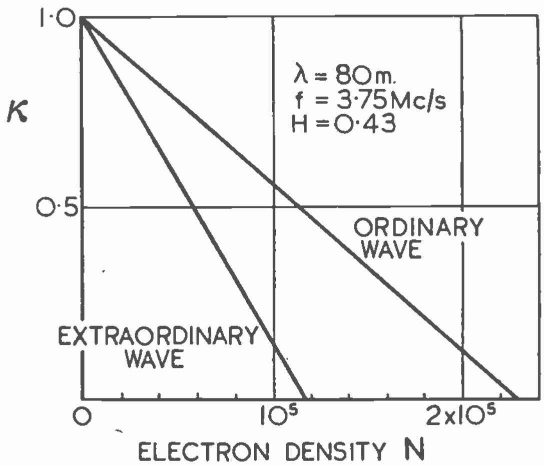

Fig. 5.

a gradual rotation of the plane of polarization as it penetrates into the ionosphere. Owing, however, to one wave being more damped than the other, the two rotating vectors become of different lengths and consequently give a resultant even when they are in opposition, thus converting the plane polarized wave into an elliptically polarized one. If one of the circular component waves is entirely damped out, as we have seen may happen to the extraordinary wave, the other continues alone as a circularly polarised wave.

As the two components of the waves of the group penetrate into the ionosphere the electron density N increases. Figure 5 (p. 41) shows for a particular case how κ varies as N increases for the two component waves; in this case H is taken as 0·43 and the wave-length λ as 80 m., corresponding to a frequency of 3·75 Mc/s. The extraordinary waves have the higher phase and lower group velocity, and with increasing N this difference may be enough to enable the group of ordinary waves to get quite clear ahead of the extraordinary group and thus produce two separate pulses circularly polarised in different directions. If this were the only thing tending to split the pulse into two, the ordinary pulse would always be the first to return to the earth. The time spent in the ionosphere depends, however, not only on the speed of the wave but also on the distance it has to travel before being reflected. Reflection occurs when $\kappa = 0$, that is, when $\omega_0^2 = \omega^2 \pm \omega\omega_m$; the upper sign refers to the ordinary wave and for this ω_0^2 will be bigger than for the lower sign. Since ω_0^2 is proportional to the electron density N, it means that the ordinary wave has to travel further into the ionosphere before reaching an electron density sufficient to cause reflection. Hence, the extraordinary pulse is reflected and begins the return journey, leaving the faster moving ordinary pulse to penetrate further into the ionosphere until it reaches a region of sufficient density to reflect it, or, failing that, passes through the layer and is lost.

These conclusions were fully confirmed by the experimental results obtained by Appleton and the band of workers inspired and guided by him. At night they found that as the frequency was increased from 2 to about 4 Mc/s the ordinary wave was increasingly delayed as compared with the extraordinary wave, until the difference corresponded to a difference of height of nearly 150 km. When the frequency reached about 4·25 Mc/s the ordinary wave failed to return, and at nearly 5 Mc/s the extraordinary wave also vanished, it having then reached the same equivalent height of about 500 km.

It was also found that at a constant frequency of 3·75 Mc/s the more penetrative ordinary wave failed to return in the evening about two hours before the extraordinary wave vanished, and at sunrise the latter appeared about half an hour before the former. These experiments were made in London by transmitting vertically upwards from one College and receiving the reflected pulses at another College about three miles away. Figure 6 is reproduced from an oscillographic record obtained in these experiments at a frequency

Fig. 6.

of 3·75 Mc/s. The first peak is the ground ray which has just travelled the three miles along the ground; this is followed about 2·5 milliseconds later by two echoes, the first being the extraordinary and the second the ordinary, as was determined by measurements made to determine their direction of rotation. The waves are then reflected from the earth and repeat the double journey and another pair of echoes arrive, the interval between the extraordinary and the ordinary pulse being, of course, doubled. Owing to its greater penetration into the ionosphere, the ordinary wave not only arrives later but is slightly more damped than the extraordinary. The wavy line is a timing oscillation of accurately known frequency, viz. 1,115 c/s.

In conclusion, it should be noted that no attempt has been made to deal with any of the spectacular war-time developments of radio; the foregoing is simply a picture of what happens to a wireless wave during its passage through the ionosphere. A realisation of the complexity of the phenomena involved can only add to one's marvel at the wonderful results obtained in long-distance radiotelephony and broadcasting which are only possible because nature has provided the earth with this ionospheric envelope in which the electromagnetic waves undergo such strange metamorphoses.

GRADUATESHIP EXAMINATION

PASS LIST—NOVEMBER 1946

124 candidates entered for the November examination, making a total of 253 for the year, as compared with 261 candidates during 1945.

A further Pass List will be published after scripts from Overseas Centres have been examined.

Passed entire Examination

The following list includes candidates who are exempt from, or who have previously passed, part of the examination and who have now passed the remaining subjects.

BAKER, Ransome Charles (S)	Mitcham, Surrey
BEAUCHAMP, Kenneth George (S)	Coventry, Warwicks.
BROADBERRY, Noel Edward (S)	Dublin, Eire
CANNON, Charles William (S)	Mitcham, Surrey
CHING, Frederick Douglas (S)	Auckland, N.Z.
CROSSLAND, Walter	Richmond, Sy.
DICKMAN, Matthew Colin (S)	Johannesburg, S.A.
FIGGEST, Harry John (S)	Tooting, S.W.17
HAMILTON, William Ian (S)	Warrington, Lancs
HERSEE, George (S)	Finchley, N.2
HIGHAM, Edward Hall	Sale, Cheshire
HIPPLE, Henry (S)	Liverpool
JARDINE, William (S)	Chislehurst, Kent
JUBBLE, Pal Singh (S)	Wood Green, N.22
MASEYK, Norman Leslie (S)	Wellington, N.Z.
MICHIE, Joseph Lawrence (S)	Skelmersdale, Lancs
McNAMARA, Stanton (S)	S. Australia
MILLETT, David Trevor (S)	Westcliff-on-Sea
MOTT, Richard John (S)	Edgware, Mddlx.
NAWIESNIEK, Jav Augustyn (S)	London, N.5
O'CONNOR, John (S)	Watchet, Som.
O'HIGGINS, Colm (S)	Dublin, Eire
PECK, Charles Owen (S)	Cambridge
PRADHAN, Kishav Valkrishan (S)	India
RINDNER, Wilhelm (S)	Tel-Aviv, Palestine
ROBINSON, Raymond Gray R. (S)	London, W.5
ROTTENBERG, Robert Ruben (S)	Cairo, Egypt
RUSSELL, Eric Victor (S)	Morecambe, Lancs
SHACKLE, George Edward (S)	Bolton, Lancs
SMITH, Roy Edward	Portsmouth
TAAFFE, Peter Albert (S)	Muswell Hill, N.10
THOMPSON, Robert Frederick (S)	Durban, S.A.
TURNER, Charles William (S)	Ludlow, Shropshire
VALENSIN, Fernand (S)	Cairo, Egypt
WALTER, Norman Edward	Nairobi, W.A.
WHYTE, Ian (S)	Bletchley, Bucks
WILKINSON, Leslie	Sheffield, Yorks
WOOLFALL, Richard (S)	Kenya Colony

Passed Part 1

CLARKE, Gerald Patrick (S)	Dublin, Eire
FORREST, Michael Augustus (S)	Manchester
GILL, Owen John (S)	London, W.14
KING, Kenneth Maurice (S)	Exmouth, Devon
LEE, Alexander (S)	London, W.1
POOLEY, Eric Kenneth (S)	Ipswich, Suffolk
SEAR, Eric Farnborough	Portleven, Cornwall
WHITWELL, Arthur Leslie (S)	Knaphill, Surrey
WILKINSON, Stanley Henry (S)	Hounslow, Mddx
YORKE, Albert Kilpatrick (S)	Moate, Eire

Passed Parts 1 *and* 2

LANGTON, Charles (S)	Stalybridge, Ches
WILLIAMS, Peter Blundell (S)	London, N.19

Passed Parts 1, 2 *and* 3

BURKE, Derek Victor (S)	Palmers Green, N.13
DOSHI, Kantilal	India
MANNIX, Timothy Patrick (S)	Lancaster

Passed Part 2

ABOBA, Joseph Jonan (S)	Alexandria, Egypt
CAREY, Robert Langer (S)	Glenagery, Dublin
GOLDNER, Henry (S)	Barking, Essex
HAUGHEY, Patrick Joseph (S)	Leix, Eire

(*Continued on p. 44*).

Graduateship Examination—Pass List (contd.).

MARSHALL, Raymond Victor (S)	Allestree, Derby
PINTOFF, Edward (S)	London, E.5
SZYMANSKI, Roman (S)	Devonport, Devon

Passed Part 3

GAVIN, Kenneth Turnbull (S)	Middle East Forces
GILLETT, William Francis Herbert	Wembley, Mddx
MASON, Eric Boyle (S)	Stockport
MEEK, Charles (S)	Glasgow
MITCHELL, Albert Ross	Shrewsbury
RAGUNATH RAO, Arina L. N. (S)	India
ROMERO, Leroy Eden (S)	London, E.17
SPENCE, Douglas Boyle	Montreal, Canada
WARD, Douglas Arthur (S)	London, N.13

Passed Parts 1, 3 and 4

ATKINSON, Thomas Leslie (S)	Whitley Bay, Northumberland

Passed Parts 2 and 3

DOHERTY, James Andrew (S)	Dublin

Passed Parts 2, 3 and 4

MURISON, Stanley Chandler (S)	Surbiton, Surrey

Passed Part 4

BROWN, Ronald Henry	Cranford, Mddx

NOTICES

Diploma in Electronics

The University College, Southampton, has decided to initiate an advanced course in Electronics, lasting one academic year (9 months) and commencing annually in October. The first of these is to begin this year. While the whole field of tele-communications, ultra-high frequency techniques, etc., will be covered, special emphasis will be laid on experimental techniques generally. At the end of the course an examination will be held of a standard equivalent to that of a Special Honours Degree, and a Diploma will be granted based on the whole year's work and on the result of this examination.

" Broadcasting Stations of the World "

This is the title of a booklet recently published by Iliffe & Sons Ltd., Dorset House, Stamford Street, London, S.E.1.

The contents include :—Long and Medium-wave European Stations, with frequencies, wavelengths and powers ; Geographical list of Long and Medium-wave Stations, with frequencies ; Short-wave Stations of the World, with frequencies, wavelengths, powers and call signs ; Geographical List of Short-wave Stations, with frequencies.

Details of more than 1,000 broadcasting stations are given and space is provided for the notation of individual dial-readings.

The booklet costs 1s., 1s. 1d. by post.

British Radio Components

The British Radio Component Manufacturers have just issued a comprehensive catalogue of their products for distribution amongst overseas customers.

The catalogue has been prepared as a joint endeavour through the Radio Component Manufacturers' Federation, by whom it is issued from 22 Surrey Street, London, W.C.2.

It provides a comprehensive and informative reference book for the whole British Radio Component Industry and will prove invaluable to radio manufacturers and agents throughout the world.

The contents include an alphabetical index to radio components and the names of manufacturers. Advertisers' announcements, occupying a large section of the book, give detailed information on many products. The Text is in English, French and Spanish.