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CONTENTS

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No. 59. *March-April, 1936.*

Editor: H. M. Dowsett, M.I.E.E., F.Inst.P.
Assistant Editor: L. E. Q. Walker, A.R.C.S.

THE MARCONI TYPE R.C.56 TELEPHONE PRIVACY EQUIPMENT

*The need for an inexpensive system for providing some degree of privacy on radio-telephone circuits which do not justify the large capital layout and maintenance costs of the first grade privacy equipment has been felt for some years, and to meet this demand the R.C.*56 *Telephone Privacy Equipment has been developed. The method of obtaining privacy is the same in both the first grade equipment and that under discussion, namely, "inversion"* : but while the former employs the well-known method of modulation and demodulation, the R.C.*56 *equipment inverts by a single process of modulation.*

A complete two direction equipment including power supply switching facilities, etc., is mounted on a self-supporting rack, the dimensions of which are 30 *inches high,* 19¾ *inches wide and* 13 *inches deep.*

BEFORE describing the functions of the various parts, the general operation of the equipment may be briefly considered. Figure 1A shows a block schematic representation when the equipment is functioning as an inverter.

The speech is first restricted to the band 500 ∿ to 2,500 ∿ by means of a filter, of which the output is applied in parallel with a constant frequency of 3,000 ∿ via the grid of an amplifier, to the input terminals of a bridge-connected instrument type metal rectifier. This rectifier acts as a modulator and is followed by a band-pass filter to select the lower side-band containing the wanted signal in its inverted form ; an amplifier, to neutralise the various losses, completes the chain.

It will be appreciated that as the frequency of the oscillator is equal to the difference between the carrier frequencies of the modulator and demodulator used in the first grade equipment no difficulty will be experienced in working inverters of different types at each end of a radio-telephone link.

The Oscillator.

The oscillator is of the grid current limited type with a high value of grid-leak resistance to cause a rapid fall of efficiency with grid voltage amplitude beyond the critical point, and with the assistance of the high mutual conductance of the valve —an M.L.4—a fair degree of stability has been obtained.

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* For a discussion of the various privacy systems, see Gill, A. J., "Privacy Systems for Radio Telephony," "P.O.E.E. Journal," Vol. 24, p. 224.

Unless the privacy equipments at either end of the radio-telephone link are inverting about the same frequency there will be a loss of intelligibility and to obviate this a bank of trimming condensers is connected in parallel with the main oscillating condenser for occasional frequency adjustment.

The output arrangement consists of two resistance-transformer coupled circuits connected in such a manner as to present a large amount of attenuation between the two output circuits, so preventing direct coupling between the two directions of transmission due to a common oscillator serving the two chains as shown in Fig. 1A.

The Modulator.

It has been previously mentioned that the signal and oscillator are fed in parallel to the bridge-connected metal rectifiers. This mixing is achieved by supplying the two frequencies across opposite points of a resistance bridge one point of which is connected to the grid of the first amplifier ; a small pre-set condenser included with the bridge serving to neutralise the valve capacity. The advantage of this method is twofold in that the loss from line to oscillator is large, thus considerably decreasing the risk of cross-talk between the two directions of transmission, and that the oscillator suffers only 6 dB. attenuation in being applied to the first amplifier valve.

Ideally in this type of modulator all that should appear at the output is :—

- (A) The modulation frequencies, i.e., the upper and lower side-bands.
- (B) Double the signal frequency—depending upon the signal voltage squares.
- (C) Even multiples of the oscillator frequency—at fixed levels.
- (D) Frequencies due to the interaction between the input frequencies.

In practice there are also :—

- (E) The original signal—depending on the signal voltage.
- (F) The original oscillator frequency—at a fixed level.

Of the above products only the lower side-band of (A) is wanted, the remainder being contributory to distortion by decreasing the wanted/unwanted ratio ; this ratio is governed by correct choice of the oscillator/signal input ratio. Besides the wanted side-band, products of less than 2,500 ∿ from (B) and (D) lie in the speech band, but again a suitable choice of operating levels renders them comparatively unimportant. The original speech also lies in the wanted band and can only be suppressed by the rectifier balance and a high oscillator/signal ratio. Hence the modulator is used near its maximum load capacity and the rectifier balance improved by taking the output from between one fixed terminal of the rectifier and the slider of a potentiometer connected in series with two of the elements. The frequencies represented by the upper side-band of (A), those above 2,500 ∿ of (D) and the whole of (C) and (F) can be suppressed by a filter.

Filters.

Another source of distortion, known as reverse inversion, must be considered : this is caused by input signal frequencies greater than 3,000 ∿ appearing at the output as low frequencies in the speech band. An example will make this clear. In a radio-telephone link with an inverter at each end, an input signal of 4,000 ∿ to the first inverter will appear at the input of the second as 1,000 ∿ and at the final output as 2,000 ∿—a spurious frequency degrading the circuit. The input inverter must therefore include precautions against such possibilities.

Having discussed the various causes of distortion and methods of their reduction, it is now possible to formulate requirements for the filters as follows :—

At the input—

- (A) To restrict the signal band to 500-2,500 ∿.
- (B) To attenuate all frequencies above 3,000 ∿ sufficiently to prevent " reverse inversion."

At the output—

- (C) To suppress the original oscillator frequency.
- (D) To suppress the double of the oscillator frequency.
- (E) To eliminate the upper side-band.

From these requirements it will be realised that the filters must of necessity be complex and costly structures, unless other parts of the chains can be made to assist. A great saving has been effected by suitably modifying the input transformers of the amplifiers to function as high-pass filter sections, cutting off at about 250 ∿ These modifications help to simplify the input filter considerably, the input transformer assisting in the restriction of the speech band at the low frequency end, while that in the output amplifier attenuates those frequencies below 250 ∿ which are caused by inverting frequencies between 3,000 and 3,250 ∿. The input filter may be reduced to a low pass filter cutting off at 2,500 ∿ and offering enough attenuation to frequencies above 3,250 ∿ to prevent appreciable " reverse inversion."

The input filter used cuts off at 2,500 ∿ and attenuates all frequencies above 3,300 ∿ by at least 30 dB., while the output filter has the same cut-off frequency but attenuates the oscillator frequency by 80 dB. and all frequencies above by more than 55 dB. The nominal impedances match the remainder of the equipment.

Amplifiers.

There are two amplifiers in each chain, an input and an output, which, with the exception of that at the output of the transmitting chain, are of one stage. The input amplifier is to ensure the correct level of the oscillator/signal input ratio being maintained for the satisfactory operation of the modulator, and the output amplifier to counteract the various losses in the component parts of the chain.

To ensure the full modulation of the radio transmitter the gain of the transmitting chain has been increased some 12 dB. by adding an extra stage of amplification to the output amplifier.

Complete Equipment.

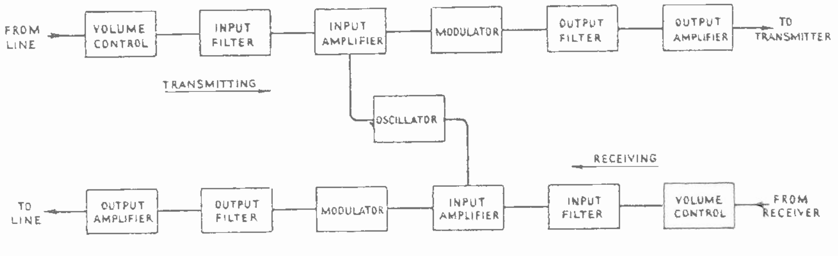
A pair of linked keys is provided for switching the privacy facility out of circuit Fig. 1A shows a block schematic of the equipment with the keys (which are not shown) set to " Privacy " and Fig. 1B the arrangement for the " Normal " position. Upon comparing these figures it will be seen that with the operation of the keys from " Privacy " to " Normal " three distinct changes are made in the transmission chains, as follows :—

- (A) The plate voltage is removed from the oscillator valve—for convenience Fig. 1B shows the oscillator outputs disconnected.

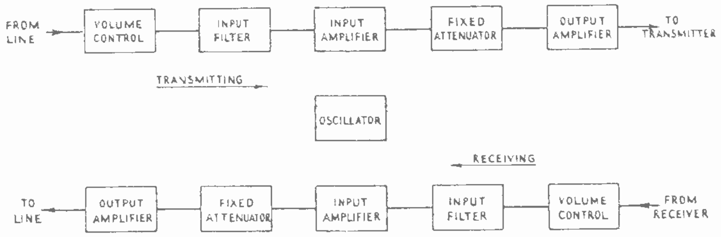
(B) A fixed attenuator pad is substituted for the modulator, the value having been so chosen that the transmission equivalent does not vary by more than ± .5 dB. at the mid-band frequency when the keys are switched from one position to the other.

(C) The output filter is removed from circuit, since in the normal condition an input signal suffers no frequency change and therefore frequencies in the region of the filter cut-offs would otherwise encounter a double amount of attenuation with consequent degradation of intelligibility.

With the exception of the gain of the transmitting output amplifier both chains are identical.



A. INVERTED.



B. NORMAL.

FIG. 1.

Performance and Operating Levels.

Fig. 2 shows the frequency characteristics of a typical chain in both the inverted and normal conditions, the equivalents being shown in dB. with reference to the mid-band frequency to make them applicable to both the transmitting and receiving chains.

From the remarks made in connection with the modulator it will be apparent that the most satisfactory operating condition for keeping the unwanted products at a minimum is to obtain as large an output as possible without overloading the amplifiers; the optimum levels are 12 dB. above a milliwatt and one milliwatt for the transmitting and receiving chains respectively when the unwanted frequencies are then 26 dB. below the wanted.

By means of the volume controls at the input to each chain the transmission equivalents can be varied over a range of 40 dB. in steps of 2 dB. ; the transmitting chain, from a gain of 10 dB. to 50 dB., and the receiving chain from 7 dB. loss to 33 dB. gain, with the maximum permissible output levels already mentioned.

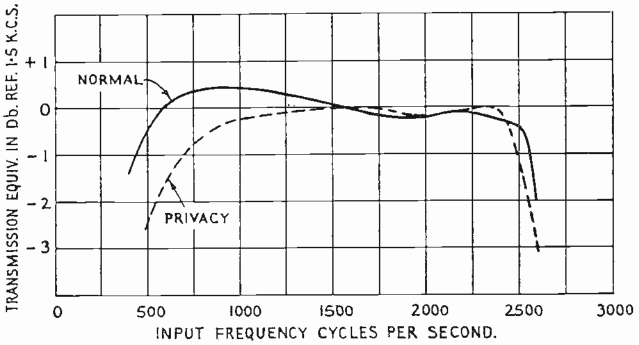


FIG. 2.

Mechanical Construction.

The chief point of constructional interest is the size ; a complete two directiona equipment, including supply control, metering and distribution panels, is mounted on a self-supporting rack, the overall dimensions being : 30½ inches high, 19¾ inches wide and 13¾ inches deep. The smallness of these dimensions is due not only to the circuit design, but also to the use of special filter coils and the adoption of chassis mounting throughout.

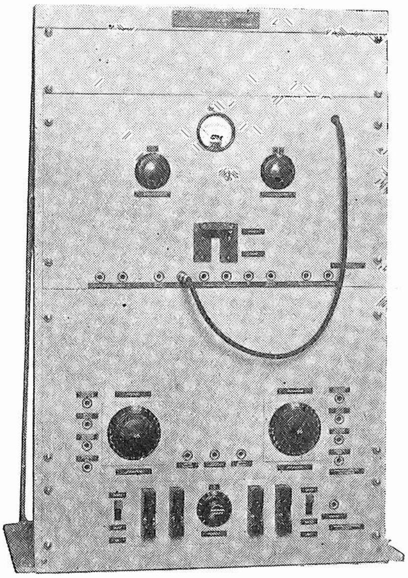


FIG. 3.

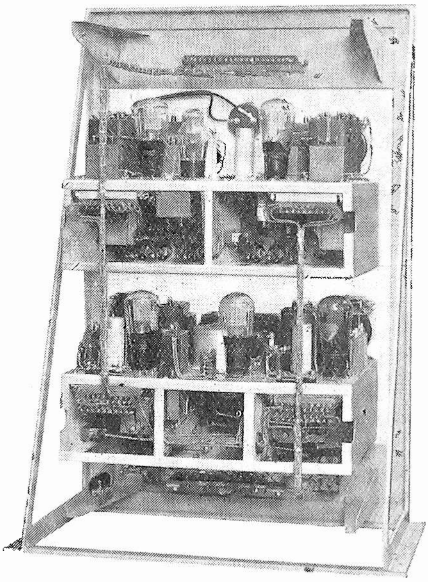


FIG. 4.

The equipment has been designed so that the mechanical layout follows the circuital order ; at the base of the rack is the supply switching panel and next above it that designated " input and control," upon which is assembled the volume controls, input filters and amplifiers and the oscillator. Above this latter panel is the " modulation and output " panel (which provides accommodation for the metal rectifiers, attenuation networks, output filters and amplifiers, switching keys and meter). A distribution panel is at the top of the rack. The transmitting chain is on the right hand side of Fig. 3, which shows the front view of the equipment. Fig. 4 shows the rear view with the protective dust cover removed. In this figure the positions of the various component parts of the chains are as follows :—Lower chassis from right to left : Receiving input amplifier, oscillator, transmitting input amplifier. Top chassis: Receiving output amplifier, transmitting output amplifier.

Jacks are provided for metering the supply voltages and plate currents and for routine and maintenance tests.

Maintenance.

The maintenance requirements have been reduced to a minimum, and beyond the usual routine measurements of supply voltages, consist of two adjustments. Firstly, checking the agreement of the oscillator frequencies at either end of the radio-telephone link, by receiving the far end oscillator over the link and patching it to one of the pair of parallel oscillator output jacks, when, with the aid of head receivers, the beats between the two oscillators may be observed and, if necessary, adjusted. Secondly, balancing the modulator to eliminate the unwanted speech. For this purpose a signal is applied to the input of the chain, with the switching keys at " Privacy," and the modulator balancing potentiometer adjusted until the minimum original frequency is observed at the output. The signal for this balance may be obtained by causing the output amplifier on the second chain to oscillate ; each output amplifier being terminated in two output jacks, one of these is patched to the amplifier input, while its fellow provides the input to the chain under test.

Conclusion.

The equipment can be used for either D.C. or A.C. filament supply voltages with D.C. plate supply voltages, or with complete A.C. mains operation, when a rectifier will be required. The power consumed is approximately 24 watts at 4 or 16 volts and 10 watts at 130 volts.

S. T. Cope.

MATERIALS USED IN RADIO MANUFACTURE

With the increasing number of functions that radio apparatus has to serve has come a corresponding increase in the materials used in the construction of such apparatus.

The following article discusses and enumerates very briefly the properties associated with some of the more generally used materials and the methods of testing adopted.

WE may conveniently divide materials used in radio manufacture into four groups, the selection obtained thereby being more comprehensive than would be obtained by treating each material separately, although some overlapping is unavoidable.

The groups that we shall consider are as follows :—

Group 1. Conductors.
Group 2. Constructional Materials.
Group 3. Magnetic Materials.
Group 4. Insulators.

In group 1, we may include copper, brass, aluminium, etc., in group 2, brass, iron and steels, aluminium and its alloys, wood, etc., in group 3, iron and steel, and in group 4, rubbers, mica, glass, micalex, ceramics, synthetic resins, plastics, oils, etc.

Considering group 1, copper undoubtedly takes first place on account of its high conductivity, 1.75 microhms per cm. cube, being second only to silver which is 1.59 microhms per cm. cube. Compared with silver, copper is cheap, and it is easily worked, can be soldered, and being ductile, is suitable for flexible cables. In consequence it is not surprising to find that copper wire is used wherever possible. Unfortunately copper oxidises rather readily under normal atmospheric conditions and this sometimes leads to a nasty problem. Naturally if it can be completely protected with enamel or lacquer, or inside a winding, so that the metal is not exposed, it is quite satisfactory.

Frequently, however, it is necessary to make contact with the metal at different points when in service, such as tappings on H.F. inductances. Lacquer improves the appearance, but is worse than useless for contact, inasmuch as the service engineer may not realise that the coil is lacquered, with consequent trouble. In such cases, it is a problem for the designer, whether to cover the copper with another conductor less liable to oxidise, and to maintain a good appearance, or to leave the copper uncovered and to forget what the appearance will be in a short time. If he chooses the first alternative, the metal covering will have a lower conductivity than copper—silver will rarely be considered on account of expense—and on account of skin effect the H.F. resistance of the conductor will be increased. The second alternative is very little better, for in time the oxide on the copper will become sufficiently thick to increase the H.F. resistance in a similar manner, and, worse still, the contact resistance at tapping points will become very high.

Probably one of the best solutions is to cover apparatus of this type with tin—conductivity 11.5 microhms per cm. cube—by the immersion process, in which the tin is usually less than $\frac{1}{10,000}$ of an inch thick. The appearance of the apparatus is

(B) A fixed attenuator pad is substituted for the modulator, the value having been so chosen that the transmission equivalent does not vary by more than ± .5 dB. at the mid-band frequency when the keys are switched from one position to the other.

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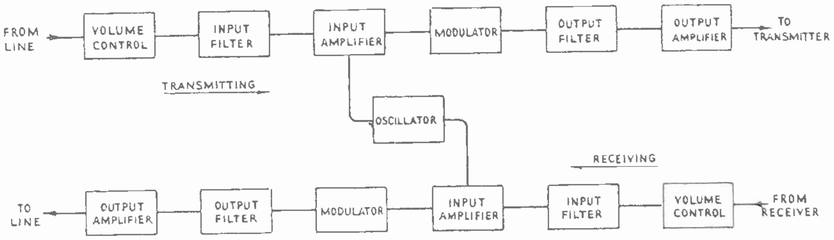
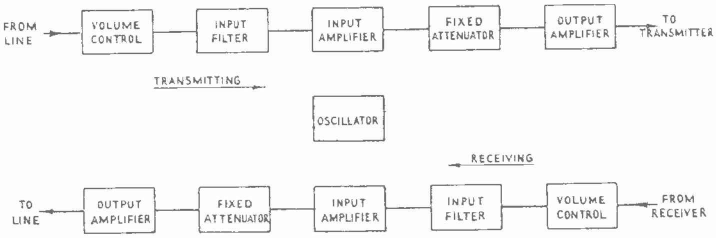


A. INVERTED.



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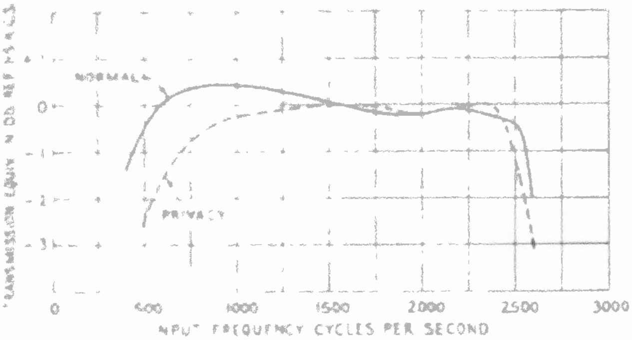

FIG. 2.

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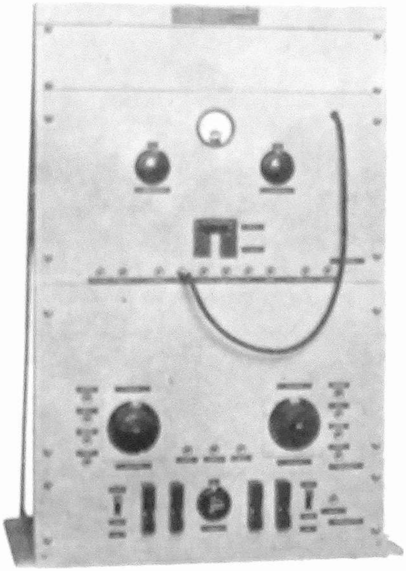
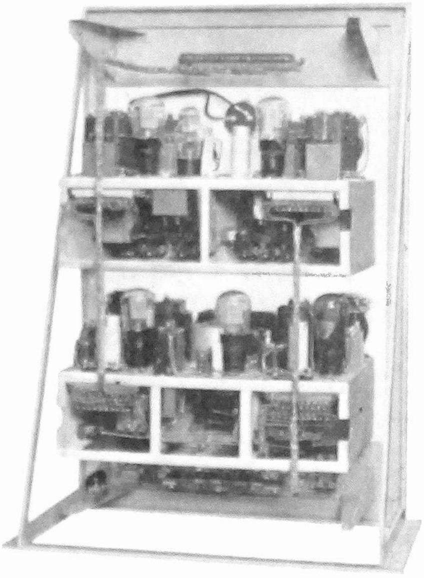


FIG. 3.



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Frequently, however, it is necessary to make contact with the metal at different points when in service, such as tappings on H.F. inductances. Lacquer improves the appearance, but is worse than useless for contact, inasmuch as the service engineer may not realise that the coil is lacquered, with consequent trouble. In such cases, it is a problem for the designer, whether to cover the copper with another conductor less liable to oxidise, and to maintain a good appearance, or to leave the copper uncovered and to forget what the appearance will be in a short time. If he chooses the first alternative, the metal covering will have a lower conductivity than copper—silver will rarely be considered on account of expense—and on account of skin effect the H.F. resistance of the conductor will be increased. The second alternative is very little better, for in time the oxide on the copper will become sufficiently thick to increase the H.F. resistance in a similar manner, and, worse still, the contact resistance at tapping points will become very high.

Probably one of the best solutions is to cover apparatus of this type with tin—conductivity 11.5 microhms per cm. cube—by the immersion process, in which the tin is usually less than $\frac{1}{10,000}$ of an inch thick. The appearance of the apparatus is maintained and the increase in H.F. resistance due to such a thin layer of tin is negligible.

There is one case in which copper conductors are silver plated, in order that the H.F. resistance shall be as low as possible, in spite of the extra expense involved. This is in the manufacture of H.F. conductors for operating at wavelengths of the order of 2 metres for medical apparatus. In connection with this point it must be realised that silver plating on copper conductors is much cheaper than complete silver conductors and is quite as efficient.

Brass.

This alloy is also used extensively for conductors where greater mechanical strength or resistance to abrasion is required, but its co-efficient of resistance is much higher—approximately 7 microhms per cm. cube. Typical examples are switch blades and contact studs, and objects of greater bulk, such as condenser vanes, panels, screens, spindles, etc., where high conductivity is not so necessary. Like copper it can be soldered easily, and oxidises on exposure, but the solution of this latter problem is more simple than with copper, for it is rare that tapping points are required on brass components in service. They can therefore usually be covered with a protective coating, which may be an insulator.

Aluminium.

Aluminium is a very good conductor—2.82 microhms per cm. cube—and is cheap. These are two points which should ensure a more general use than actually exists, but it has serious disadvantages. Aluminium is a soft but brittle metal, of low tensile strength, cannot easily be soldered, and is very prone to electrolytic action with other metals under humid conditions. At one time it was used extensively for condenser vanes, but due to its softness has mostly given way to brass in this class of apparatus.

In the pure state, i.e., 99.8 per cent., which is a commercial product, aluminium is practically unaffected by atmospheric conditions when not in contact with other metals.

The *apparent* immunity of aluminium to oxidation is due to the fact that its oxide, which forms very rapidly, is transparent, and this oxide skin prevents further action in the case of the pure metal.

A useful feature of aluminium is its low specific gravity, but this is more a point to be considered in construction.

This factor brings us to the second group, namely, that of constructional materials.

Iron and Steel.

In this respect iron, on account of its cheapness and tensile strength—20 to 25 tons per square inch—is used wherever possible—probably more so than any other material for constructional purposes. It is comparatively easy to work, and certainly the best material to weld. Frameworks for commercial receivers and long wave transmitters are rarely made of anything else. The rapidity with which it oxidises is well known, so it always requires some effective rustproof covering, and commercial iron has such a rough surface that considerable finishing may be required.

Mild steel takes the place of iron for panel and cabinet work where better finishes are required, owing to its smooth surface, and also for chassis and small constructional work where greater mechanical strength can be obtained for the same bulk. The tensile strength of mild steel is 35 tons per square inch. It can be machined easily and offers no difficulties to welding. Like iron, it oxidises rapidly and so must be effectively rustproofed.

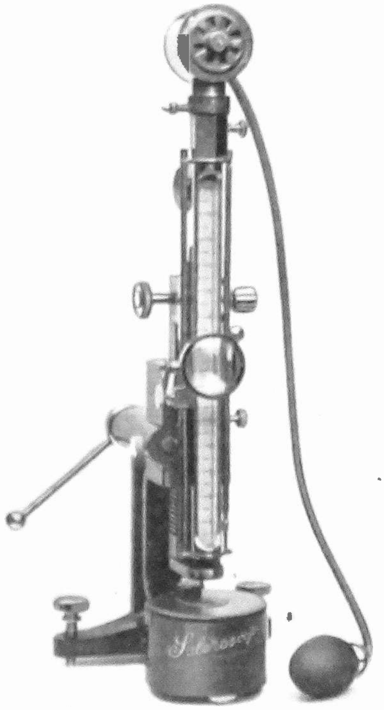


FIG. 1.

Scleroscope used for testing hardness of materials.

Mild steel cannot be hardened and tempered, but a hard skin can be produced quite simply by case hardening where greater resistance to abrasion is required. Alternatively, plating with chromium is very effective for producing a hard surface which is not affected by corrosion. It may be pointed out here that chromium plating on mild steel can be obtained which is harder than glass.

Cast steel is not used to any great extent, for its property of being hardened and tempered is not much suited to radio manufacture. It is less liable to oxidise, so for spindles, etc., it is usually not treated in any way. By hardening, its tensile strength can be raised to as much as 140 tons per square inch. In the form of fine wire this figure can be increased to 200 tons per square inch, but decreases as the diameter of the wire increases. This is due to the fact that fine wire passes through the die several times and so becomes more homogeneous.

Stainless steels, e.g., those containing chromium and nickel, are coming into general use for apparatus liable to exposure, where resistance to corrosion and mechanical strength are the main considerations.

At first it was practically impossible to machine stainless steel, for it was extremely hard and could not be tempered. Now Austenetic stainless steel is used, which can be machined, but with difficulty. A curious feature of this material is that it is non-magnetic.

Brass.

Brass is a close rival to iron in construction, due in many cases to the fact that it is also part of the conductor system. Another main point is that for short wave sets, and long wave also where the H.F. inductances are in close proximity to the framework, the losses are much lower than would be the case if iron were used. It is also used considerably for screening H.F. circuits and for H.F. chassis construction.

It is much more expensive than iron, and the specific gravity is a little higher, so that it should not be used prodigally. The correct type of brass must always be chosen for the particular job. Bending quality must be considered where bends are required, a short grained brass—such as Delta metal—must be chosen for machining, a hard rolled brass for flat sheets, etc. Brass is not a good metal for castings, and for appearance it is essential that the finished article be covered in some way to prevent oxidising and discolouration.

Aluminium.

The main use of this material is in the construction of frames, cases, etc., for portable and aircraft apparatus where total weight is a major consideration. Unfortunately, even in the hard state its maximum tensile strength is only 13 tons per square inch and it is still quite soft. Also it cannot be satisfactorily soldered, for although a soldered joint is strong for a time, it deteriorates rapidly, and in a few months is practically useless. This is due to the fact that the solder used, necessarily has a lower melting point than aluminium, and electrolytic action is set up between the alloy metals in the solder and the aluminium. With care it can be welded, and in this case the welding rod used is formed from a strip cut off the material, so the electrolytic action is avoided and the joint is sound. Some of the afore-mentioned objections have been overcome by the use of aluminium alloys, and at the same time the specific gravity has not been increased greatly. Duralumin, which is an aluminium-copper alloy, is one of the best known of the above, and has a tensile strength of 26-35 tons per square inch, so by using this alloy the strength of mild steel can be obtained with approximately one quarter of the weight. A curious feature of duralumin is that it can be annealed by heat treatment, but returns to the normal hard condition in a very short time.

Actually two hours is the limit for bending after annealing, and although it has not returned entirely to normal by that time, the figure gives a very good indication of the rapidity with which it is self-hardening.

Birmabright is very similar to duralumin, but is an aluminium-magnesium alloy, and the tensile strength is lower being only 18-30 tons per square inch. It can be obtained in hard, normal or soft condition.

For castings, aluminium zinc and aluminium silica are used for cases of ship receivers, pedestals, etc. They are hard, but the tensile strength is only about 15 tons per square inch.

Aluminium bronze is an excellent alloy for castings, has a tensile strength of 30 tons per square inch, can be bent, and is very resistant to abrasion. Its specific gravity—7—is higher than other aluminium alloys, but in view of its other excellent qualities it is rather surprising that it has not found more use in radio manufacture.

Wood.

Except for military equipment, wood has been superseded for general frames and cases, and where used is almost entirely for decoration. The risk of fire has undoubtedly helped to reduce its use.

Teak is universally used for military equipment, being the only wood which does not suit the palate of the white ant.

An exception to the gradual elimination of wood is its continued use for skeleton inductance formers, especially on high power sets, where the presence of any metal not included in the circuit causes objectionable overheating, and wood construction is eminently suitable. Incidentally, well dried wood, particularly American Whitewood, is also a good H.F. insulator, but is so absorbent that difficulty is experienced in keeping it dry. Some engineers have given up attempting to prevent absorption and use the wood uncovered in any way. When the transmitter has been shut down for any length of time, it is run for a while on low power, the wood warms up, due to the presence of the moisture and drives the moisture out. Then when the power is raised, there is no further heating, and actually the wood cools down.

Magnetic Materials.

In the third group we shall only consider iron and steel. The irons having high permeability and low retentivity are probably the most used, for transformer cores, etc. Of these " Stalloy " has been satisfactorily used for power frequencies for a very long time, and was generally adopted for audio frequency transformers. Greater fidelity in reproduction necessitated improved iron circuits in these transformers, especially at the higher frequencies. The result was the production of Laminic, Radio Metal, Mumetal, etc., which are nickel-iron alloys, having greater permeability and lower retentivity than stalloy. Armco iron is similar, but is used more for relays, etc., in solid form, as distinct from similar laminated components.

All these latter metals have one very serious disadvantage, in that they require heat treatment after any machining operation, otherwise nothing is gained by using them. This heat treatment is at 1,100 degrees to 1,150 degrees C., with consequent scaling unless special precautions are taken, such as a nitrogen atmosphere. Quite recently a Swedish firm has placed on the market a very soft iron which is almost chemically pure. The great advantage of this material is that it is generally as good as Armco iron in the annealed condition. It is doubtful if it will replace stampings of nickel-iron alloys where very thin material is used, for being so soft, it would be difficult to assemble, but for transformer boxes, relays, etc., it should be very welcome.

Ferrocart was produced to be suitable for high frequency circuits. It consists of finely divided particles of iron, packed closely to, but insulated from one another, thereby reducing hysteresis to a minimum, but at the same time reducing the permeability to a very low value (approximately 8). Nevertheless, when used in windings of H.F. inductances it improves the efficiency. Firstly, much less wire is necessary for the same inductance, so copper losses are reduced; secondly, a much smaller coil is produced, and thirdly, screening can be placed quite close to the coil without affecting the efficiency because the iron circuit concentrates the field. Incidentally if coils are required without screening, iron cored coils can be placed closer together without interaction. Experiments have been tried with Ferrocart cores in transmitting inductances without much success. When the ampere turns are increased beyond a certain figure, the structure of the Ferrocart collapses and is reduced to dust.

Steels are used in magnetic circuits on account of their retentivity in the glass hard state. Ordinary cast steel is quite good, but usually special steels are employed. They are used for the manufacture of permanent magnets for telephones, loudspeakers, relay instruments, the ribbon microphone, etc. They are also used in recording tape apparatus of the Blattnerphone type.

Insulating Materials.

These materials are used in greater variety than in any of the other groups, and it will be necessary to reduce the selection to the better known ones.

Before giving the properties of each material individually, a few general points regarding requirements and tests will be considered.

First and foremost it is essential that the material is an efficient insulator for the potentials which are to be applied and that breakdown does not occur. The breakdown is taken through the material, for although it is interesting to know the breakdown voltage between two points on one surface, it is of little practical value, for the breakdown voltage can never exceed that between points similarly spaced in air, unless, of course, the material is required for apparatus to be immersed in oil, when the test must be carried out under similar oil.

In the case of breakdown between electrodes on opposite sides of the material under test, very varied results are often obtained. But the breakdown voltage is dependent upon several conditions, one is the size and shape of electrodes, and another point to be remembered is that the relationship between breakdown voltage and thickness is not linear. The first of these points can be overcome by always using the same electrodes, and the second by always testing the same thickness of material. This is not always possible, but a useful formula has been found by several experiments to account for this for a large number of materials, and although it is not universal, it is quite a good guide.

The formula is $V = Ad^n$

where V = breakdown voltage
d = thickness of material

A and n are constants, dependent upon the material, the size and shape of the electrodes, frequency of test voltage, atmospheric conditions and duration of test.

n is invariably less than unity, and for any particular material if this figure is 0.5 (a normal value) it is easy to see that under similar conditions, an increase in thickness of 100 times will only increase the breakdown voltage 10 times.

Similarly if the thickness is reduced 100 times, the breakdown voltage is only reduced 10 times. Thus in some cases phenomenally high breakdown voltages are obtained with very thin material. In fact it is possible to produce a 2 mfd. condenser capable of withstanding 3,000 volts D.C. with two electrodes about 1 in. in diameter, with glass dielectric of order of .0001 in. thick. At present little use is made of this phenomena, and this may be due in some extent to the fact that text books express breakdown as volts per centimetre, which information is of little use and very misleading unless the thickness of the test piece is given.

Next it is necessary to know the dielectric constant and the losses expressed as a power factor. Both these facts are obtained on a "Shearing" bridge at 800 or 1,000 cycles, the former by measuring the capacity of a condenser with the test material as dielectric, calculating the capacity of the same condenser with air dielectric and dividing the second result into the first. Under humid conditions the dielectric constant of absorbent materials is always higher, due to the water present whose S.I.C. is very high, so no result can be relied upon when the humidity is greater than about 75 per cent.

The power factor is obtained directly from the readings obtained on the "Shearing" bridge, and is generally expressed as a percentage. There is often much discussion about the power factor of dielectrics, but it must be remembered that the only power used is due to losses, and that therefore a perfect dielectric has no losses and consequently zero power factor. The actual reading on the "Shearing" bridge gives $\tan\theta = R\omega C$, but this is sufficiently accurate for very good materials, where θ is very small and $\cos\phi$ is approximately equal to $\tan\theta$. When the losses are high, it is not surprising that power factors of the order of 140 per cent. are obtained. In German technical papers this figure is called the "tan of the angle of loss," which is self-explanatory and a far more acceptable term.

Having obtained the power factor of a material at 800 cycles, it is quite reasonable to assume that by obtaining the power factor at various frequencies, the best possible information will be available. Unfortunately this is not true, but the results are useful up to a point and quite interesting.

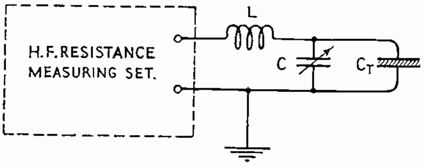


FIG. 2.

With this object in view a series of results for $\tan\theta$ were obtained by the author at various frequencies up to 5,000 kilocycles. Measurements of high frequency resistance of condensers were made with various dielectrics with the circuit shown in Fig. 2 in conjunction with the high frequency resistance bridge. The resistances of a tuned L.C. circuit were measured, then C_T (the condenser with sample as dielectric) was added, C retuned, and the added resistance due to C_T obtained. From this result the true H.F. resistance of C_T can be obtained from

$$R_{HF} = \frac{R\,(\text{added}) \times C^2\,(\text{total})}{C_T^2}$$

from which

$$R\omega C_T = \frac{R\,(\text{added}) \times \omega C^2\,(\text{total})}{C_T}$$

The first point observed was that the dielectric constant of most materials decreased as the frequency increased, and also increased as thickness decreased at any frequency, approaching the low frequency value with very thin material. Also, it soon became evident that quite appreciable variations in results were obtained by changing parts of the apparatus, so that the results could only be comparative. However, the results obtained were quite interesting and showed that generally as frequency increased, so the power factor decreased, then as frequency was further increased the power factor increased, indicating a definite best frequency for each material. Over the range of frequencies on which tests were carried out, only a few of the materials gave these results definitely.

German experimenters mostly give $\tan\theta$ as the behaviour of materials at various frequencies, and some amazingly low figures are given, and no doubt obtained.

There is a very definite reason for not relying entirely on these results given by manufacturers or obtained in independent laboratories.

It was observed with one ceramic material that the losses were high when used on power circuits, although the power factor measurement at high frequency was extremely low. This was then found to be the case with many other materials, and in consequence it was necessary to test them all on power circuits.

After much preliminary work it was decided to adopt 20,000 kilocycles as the general test frequency, this being the highest frequency at which the materials were likely to be employed.

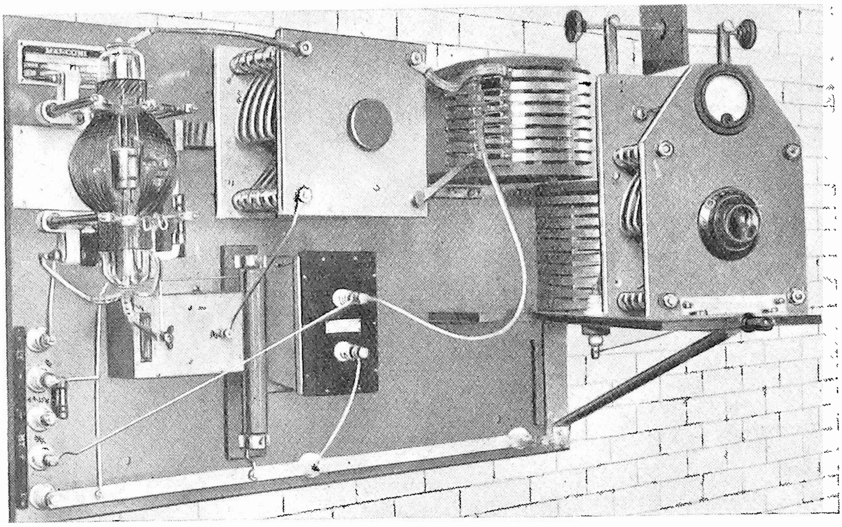


FIG. 3.

Also it was found that 2,000 volts applied to specimens ¼ in. thick, for 10 minutes, gave very good comparative readings by measuring temperature rise, and moreover readings which could be relied upon. The same electrodes must always be used. It is not necessary to determine actual breakdown voltages at high frequencies, because heating commences long before breakdown, and the problem is really reduced to keeping the material cool. The apparatus used is shown in Fig. 3 and a circuit diagram in Fig. 4.

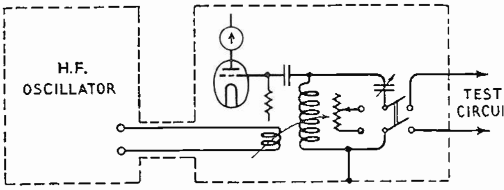


FIG. 4.

Although several materials give excessive heating under this test, they are not necessarily rejected entirely, for they are often quite satisfactory at, say, 2,000 kilocycles, and accordingly tests are continued until this satisfactory frequency is determined.

For materials to be used at frequencies above 20,000 kilocycles, special tests are required and these have not yet been standarised, but samples are tested with a view to the particular job in question.

Having considered the electrical requirements, it is very necessary to deal with the other properties of the materials.

Taking the accepted figure of 100 degrees F. for permissible temperature rise on apparatus, for general requirements material must not soften, warp or melt at this figure. In special cases this may be reduced, when it is known that the temperature rise will be very low.

Then the absorption must be found and also the behaviour under tropical conditions. These two tests are carried out simultaneously by placing the material in a steam chamber at 140 degrees F. for two hours. The weight before and after will give the absorption, and the effect of the hot moist conditions noted.

It has often been argued that this test is far too searching, and that similar conditions are never found on this planet. This is true to some extent, but test results are required quickly, and it requires a very strict test to determine the differences between really good materials.

The mechanical strength is another important point; rarely is it necessary to know the tensile strength, and this is in any case usually given by the manufacturer when submitting samples. But it is very necessary to know how brittle the material is. The test used consists of clamping one end of a definite size sample in a vice in a horizontal position, passing a rod through the free end, and allowing known weights to fall a known distance down the rod.

If necessary, the actual force required to fracture can be obtained, but the results required are only comparative, and it is equally useful to quote the fall of a certain weight when fracture occurs. Several methods have been tried, and this gives the most consistent and reliable results.

Most of these materials are sold by weight, so from the point of view of cost per square foot the specific gravity must be taken.

Let us next consider the materials individually.

The rubber group, consisting of pure rubber, vulcanised rubber, ebonite, keramot and composite material to specification WT.22 are perhaps the best known.

Pure Rubber. This has the following constants :—

Breakdown Voltage	160—500 KV. per cm.
Dielectric Constant	2.5.
Power Factor at 800 cycles ..	.4 per cent.

It is very flexible and its chief use is in the manufacture of cables, adjacent to the wire, to protect the wire from the action of the sulphur in the vulcanised rubber covering. Its great disadvantage is that it perishes in a very short time, thereby reducing the breakdown voltage of the cable appreciably.

Vulcanised rubber is used for the insulation on cables and is much harder than pure rubber and does not perish so quickly, but is still quite flexible. However, it is not advisable to use it continuously at temperatures exceeding the normal of this country.

Ebonite was at one time universally employed as an insulator throughout transmitters and receivers, but has now been superseded in many cases by more suitable materials.

Ebonite possesses the following constants :—

Breakdown Voltage	300—1,100 KV. per cm.
Dielectric Constant	2.7.
Power Factor at 800 cycles	.25 per cent.
H.F. Temperature rise at 20,000 KC. ..	12° F.

From these figures it will be seen that electrically it is not seriously lacking, but it warps at a low temperature (140 degrees F.) and discolours in a short time. The absorption is very low, being less than .01 per cent.

" Keramot " is a loaded ebonite with very similar electrical properties to ebonite, but does not warp until about 175 degrees F. and does not discolour.

" WT.22 " is a more heavily loaded ebonite, which does not warp until 215 degrees F. The absorption is a little higher but still less than .01 per cent.

Its electrical properties are :—

Breakdown Voltage	500—1,000 KV. per cm.
Dielectric Constant	2.8.
Power Factor at 800 cycles	.2 per cent.
H.F. Temperature rise at 20,000 KC. ..	3° F.

Unfortunately it is much more brittle than ebonite.

Mica, one of the best known insulators, cannot be ordered to specification, but only as nature cares to supply it. Consequently, large thick sheets cannot be obtained, and its use is limited chiefly to dielectric in condensers.

Breakdown Voltage	1 mm. 300—700 KV. per cm. .1 mm. 1,500—2,000 KV. per cm.
Dielectric Constant	5.5—6.
Power Factor at 800 cycles ..	.1 per cent.—10 per cent.

The standard test at 20,000 KC has not been applied, but from results obtained in practice it is accepted as a good insulator at that frequency.

It is not affected by heat, unless unevenly applied, when it flakes and cracks, but its point of fusion is not known.

Glass varies considerably and the result of electrical tests given below are for plate glass :—

Breakdown Voltage	300—1,500 KV. per cm.
Dielectric Constant	5—8.
Power Factor at 800 cycles	.4 per cent.
H.F. Temperature rise at 20,000 KC. ..	15° F.

When the formula for breakdown voltage, namely $V = Ad^n$, is applied to glass, n is very low, and thick sheets of glass break down at comparatively low voltages. Another thing about glass is that when mechanical stresses are applied the electrical properties are lowered. A particular case is that of " armour plate " glass, which is extremely flexible, but the power factor is 4 per cent. and H.F. temperature rise 80 degrees F.

" Micalex " is a mixture of mica and glass. The mixture is raised to a temperature at which the glass fuses and allowed to cool under pressure. This pressure is very high, but it is insufficient to make the micalex homogeneous, and in consequence it is very absorbent. Figures as high as 3 per cent. and 4 per cent. have been recorded. On account of this it is practically useless for receivers and wavemeters, but for power circuits, where the moisture is quickly dried out, it is one of the most efficient insulators.

Breakdown Voltage	500—1,000 KV. per cm.
Power Factor at 800 cycles	1—1.5 per cent.
H.F. Temperature rise at 20,000 KC. ..	0° F.

It is a very good example of a material whose power factor measured at high or low frequency is of little value, but in this case the material is far better than would be imagined from power factor readings.

There is not much doubt that if the micalex could be maintained perfectly dry, then good results would be obtained by bridge measurement, but it is so fond of moisture that its losses increase within seconds of removing it from the drying medium.

The micalex used generally at present is known as " Leadless," and this term is derived from the fact that it is made from glass other than lead glass. A curious feature is that the lead micalex is far superior electrically, and the moisture absorption is comparatively low.

Although very hard, micalex can be machined with difficulty, but it is very brittle, being about twice as brittle as ebonite.

Ceramics as a group are good insulators, and have low moisture absorption properties, all being less than .01 per cent.

Porcelain, glazed and unglazed, is used extensively not only in radio manufacture, but also throughout the electrical industry, but at very high frequencies its losses increase considerably, causing heating and fracture.

" Steatite " is an improvement on Porcelain, but still heating is more than is really allowable at high frequencies. " Steatite " does not fracture when heated.

" Frequentite " is a material which gives excellent power factor readings by bridge measurement even up to 50,000 KC. and for receivers there are very few materials that compare with it. Like " Steatite," it will withstand considerable heating without fracture.

One of the main objections to all ceramic materials is that they cannot be machined, and all parts must be moulded completely, and exactly as they are required.

Synthetic Resins of the Phenol-Formaldehyde Type.

The resin itself is only used as a varnish, and where sheet is required, paper is impregnated with it.

In this form it is usually known as bakelite, paxolin, etc.

It is a good insulating material of excellent mechanical strength, and one whose electrical properties are good.

Breakdown Voltage	100—200 KV. per cm.
Dielectric Constant	1.3—3.
Power Factor at 800 cycles	1.5 per cent.—20 per cent.
H.F. Temperature rise at 20,000 KC. ..	140°—300° F.

The manufacturers of sheet claim that if the electrical properties are the best possible then the colour will not always be the same, so it is not surprising to find high and low frequency grades, in which the low has a constant colour but the high has not.

The resin is also mixed with wood pulp and made into moudlings of numerous types for both insulating and decorative purposes, but in this form it is not such a good insulator.

The varnish, i.e., the resin in a solvent, is used extensively for impregnating coils to keep out moisture, and it is more to be recommended for coils wound with cotton or silk covered wire than those wound with enamelled wire.

Other synthetic resins have more recently been manufactured, but all soften between 160 degrees F. and 200 degrees F. These are known as Trolitul, Victron and Leukon, etc.

Trolitul is a good H.F. insulator, and has very low losses up to 40,000 KC. It is transparent, moderately hard, not brittle, but can only be produced in moulded form, although small moulded sheets have been obtained.

Victron and Leukon are very similar to Trolitul in many respects. The former is usually pink in colour, and the latter is transparent. They are mainly produced in moulded form.

Wax. Paraffin wax is a really good insulator right up to 20,000 KC., but owing to the fact that it melts at 140 degrees F. and commences to soften before that, its use is rather limited. Filling in H.F. condensers was its main use, but now it has been superseded for this by waxes having higher melting points.

Small wood insulators, which must be moisture proofed, are immersed in the melted wax for some time, and this is still about the best treatment for wood.

Bitumen has replaced wax in many cases for filling apparatus where higher temperatures are encountered. It is always slightly plastic and the melting point is about 250 degrees F. Electrically it is not so good as wax, and at high frequencies it is about equal to Keramot.

Oils. Insulating oils continue to be used for transformers, switches and condensers where the size is greatly reduced by its inclusion, for the breakdown voltage between adjacent components of opposite potentials is greatly increased.

In connection with transformers, it also acts as a cooling medium, but care must be taken in design that no material used will be affected by the oil, e.g., rubber.

In H.F. condensers the size is reduced twofold, for not only can the plates be closer together without breakdown, but also the dielectric constant is about 3.

In testing oil, or components oil filled, it should be remembered that when breakdown occurs the oil carbonises, and the finely divided carbon penetrates the whole of the oil, so that in future breakdown will take place at a lower potential, and the losses will be increased.

V. O. STOKES.

ANALYSIS OF BRIDGE CIRCUIT FOR PIEZO-ELECTRIC QUARTZ RESONATORS

The equivalent electrical networks of a quartz crystal together with its holder are first examined [illegible] an analysis of the crystal bridge circuit as originally developed [illegible] J. Robinson. Certain assumptions are made in this analysis to simplify the [illegible] but these are of such a nature as to have no appreciable effect on the accuracy [illegible] the results obtained. The [illegible] agreement between the calculated and experimental [illegible] would be obtained. [illegible] intended in this paper to present a rigid mathematical analysis [illegible] but rather [illegible] present a picture of the mode of operation [illegible] the bridge [illegible] changes in the value of the balancing condenser.

BEFORE [illegible] generators used with quartz resonators [illegible] associated with the quartz crystal itself will [illegible] experimental evidence exists to enable an equivalent [illegible] the quartz crystal [illegible] circuit having electrical [illegible] mechanical dimensions of the particular crystal used. [illegible] dependent on the manner in [illegible] to the axes of the mother crystal.

A [illegible] represented by the network of Fig. 1 [illegible] expressed in terms of mechanical dimensions of a crystal [illegible] which the crystal axes are parallel to the [illegible] crystal can be represented with considerable [illegible] formulae:

K [illegible] farads

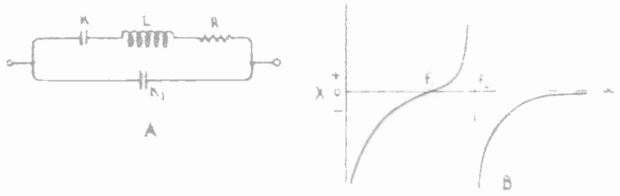
K [illegible] farads

L [illegible] henries

where [illegible] crystal dimensions in centimetres along the mechanical, [illegible] respectively.

[illegible] formula for the resistance R the practical [illegible] measured resistance is dependent on the method [illegible] vary between wide limits. The curve representing [illegible] shown in Fig. 1B. It will be observed that the [illegible] termed the series resonant frequency and infinite [illegible] resonant frequency, the magnitudes of which are [illegible] It may be [illegible] that the difference between these two frequencies [illegible] the series resonant frequency and is independent of the [illegible]

Next consider [illegible] mounted between plates the same size as the crystal faces [illegible] and any stray fields external to the crystal that may [illegible] the plates. With a centrally disposed crystal there will be two small air gaps [illegible] plates; these may be represented in a network as two small air dielectric condensers either side of the network of Fig. 1, or by a single condenser K_2 having a dielectric equal to the total air gap as shown in Fig. 2A, a typical reactance curve for such a circuit is shown in Fig. 2B. It will be seen that the reactance is now zero at some frequency f_3 higher than f_1 by an amount dependent on K_2. f_3 is now the series resonant frequency of the network. It will be observed that f_2 is unaltered by capacity due to the air gap.



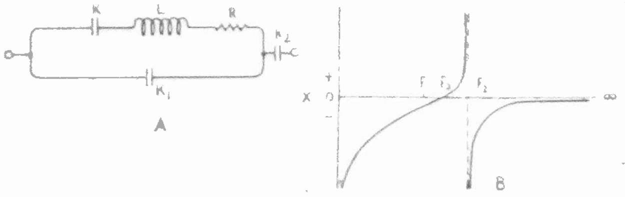
$$f_1 = \frac{1}{2\pi}\cdot\frac{1}{\sqrt{LK}} = \frac{272}{l_m}\times 10^6 \text{ cycles}$$

$$f_2 = \frac{1}{2\pi}\cdot\frac{1}{\sqrt{L\frac{KK_1}{K+K_1}}} \text{ cycles}$$

$$f_2 - f_1 = \frac{f_1}{2}\cdot\frac{K}{K_1} = \frac{978}{l_m} \text{ cycles}$$

FIG. 1

Finally, consider the crystal mounted between plates larger than itself having terminals or leads attached. The effect of such a mounting is to introduce a capacity shunting the network of Fig. 2 and may be represented by K_3 in Fig. 3A. From the reactance diagram it will be seen that the series resonant frequency remains the same as for the previous case, but the parallel resonant frequency is now reduced to f_4 by the action of the condenser K_3.



$$f_3 = \frac{1}{2\pi}\cdot\frac{1}{\sqrt{L\frac{K(K_1+K_2)}{K+(K_1+K_2)}}} \text{ cycles}$$

$$f_2 = \frac{1}{2\pi}\cdot\frac{1}{\sqrt{L\frac{KK_1}{K+K_1}}} \text{ cycles}$$

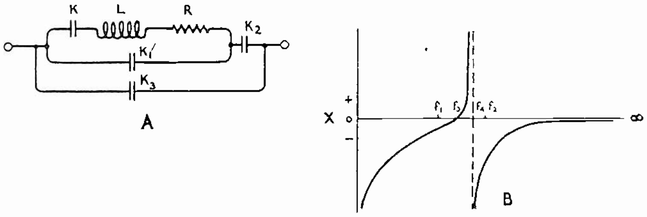
$$f_3 - f_1 = \frac{f_1}{2}\cdot\frac{K}{K_1+K_2} \text{ cycles}$$

$$f_2 - f_3 = \frac{f_1}{2}\cdot\frac{K}{K_1}\cdot\frac{K_2}{K_1+K_2} \text{ cycles}$$

FIG. 2.

Two factors therefore operate to reduce the difference between what may be termed the "natural" series and parallel resonant frequencies f_1 and f_2 of a piezo-electric quartz resonator, since an increase in the air gap results in a series resonant frequency higher than f_1 and an increase in holder capacity results in a parallel resonant frequency lower than f_2. As an example, in a 450 kC. resonator $f_2 - f_1 = 1620$ cycles, but when mounted in a holder of appreciable capacity with relatively large air gaps, $f_4 - f_3$ may be as small as 70 cycles. It will be appreciated that such a small frequency difference must result in a very steep reactance curve near the resonant frequencies.

Alteration of the crystal characteristics by alterations to the mount is an unsatisfactory method of attaining this end, apart from the limited variation obtainable. The well known crystal bridge, as used in the Stenode Radiostat circuit by Dr. J. Robinson, provides a simple and practical means of obtaining considerable variation of the characteristic. Such a bridge is shown in Fig. 4 coupled to the tuned anode circuit of a valve; the output from the bridge is coupled to another tuned circuit, auto transformer fashion. The bridge itself may be represented by the network of Fig. 5A. In what follows it will be assumed that the voltages induced in the two arms of the bridge are equal. In practice, the input inductance is generally tapped near to one end so that a relatively large balance condenser C_B (say 10 $\mu\mu f$. max.) may be used, operating well away from its minimum value. Referring to the figure, two equal voltages e, e, the phases of which are indicated, give rise to currents I_1, I_2 in the two halves of the bridge. The current through the diagonal is then $I = I_1 - I_2$. The bridge circuit may be further simplified since the impedance of the inductances shown is small compared with that of either the crystal or the balancing condenser C_B. The simplified circuit is shown in Fig. 5B. Since the network is in the form of a bridge, it is therefore possible to make $I = 0$ by adjusting the balancing condenser provided the quartz resonator acts as a capacity. It will be shown later that the



$$f_3 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L \cdot \dfrac{K(K_1 + K_2)}{K + (K_1 + K_2)}}} \text{ cycles, } f_4 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L \cdot \dfrac{K\left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)}{K + \left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)}}} \text{ cycles}$$

$$f_3 - f_1 = \frac{f_1}{2} \cdot \frac{K}{K_1 + K_2} \text{ cycles, } f_4 - f_3 = \frac{f_1}{2} \cdot \frac{K}{K_1 + K_2} \cdot \frac{K_2 - \dfrac{K_2 K_3}{K_2 + K_3}}{K_1 + \dfrac{K_2 K_3}{K_2 + K_3}} \text{ cycles}$$

$$f_2 - f_4 = \frac{f_1}{2} \cdot \frac{K \cdot \dfrac{K_2 K_3}{K_2 + K_3}}{K_1\left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)} \text{ cycles}$$

FIG. 3.

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Small wood insulators, which must be moisture proofed, are immersed in the melted wax for some time, and this is still about the best treatment for wood.

Bitumen has replaced wax in many cases for filling apparatus where higher temperatures are encountered. It is always slightly plastic and the melting point is about 250 degrees F. Electrically it is not so good as wax, and at high frequencies it is about equal to Keramot.

Oils. Insulating oils continue to be used for transformers, switches and condensers where the size is greatly reduced by its inclusion, for the breakdown voltage between adjacent components of opposite potentials is greatly increased.

In connection with transformers, it also acts as a cooling medium, but care must be taken in design that no material used will be affected by the oil, e.g., rubber.

In H.F. condensers the size is reduced twofold, for not only can the plates be closer together without breakdown, but also the dielectric constant is about 3.

In testing oil, or components oil filled, it should be remembered that when breakdown occurs the oil carbonises, and the finely divided carbon penetrates the whole of the oil, so that in future breakdown will take place at a lower potential, and the losses will be increased.

V. O. STOKES.

ANALYSIS OF BRIDGE CIRCUIT FOR PIEZOELECTRIC QUARTZ RESONATORS

[illegible]

B [illegible]

The manufacturers of sheet claim that if the electrical properties are the best possible then the colour will not always be the same, so it is not surprising to find high and low frequency grades, in which the low has a constant colour but the high has not.

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V. O. Stokes.

ANALYSIS OF BRIDGE CIRCUIT FOR PIEZO-ELECTRIC QUARTZ RESONATORS

The equivalent electrical constants of a quartz crystal together with its holder are first discussed, then [illegible] an analysis of the crystal bridge circuit as originally developed by [illegible] J. Robinson. Certain assumptions are made in this analysis to simplify the [illegible] but these are of such a nature as to have no appreciable effect on the accuracy of the results obtained. The [illegible] agreement between the calculated and experimental [illegible] is shown. It is not intended in this paper to present a rigid mathematical analysis of the [illegible] but rather to present a picture of the mode of operation [illegible] changes in the value of the balancing condenser.

BEFORE [illegible] generally used with quartz resonators, [illegible] associated with the quartz crystal itself will [illegible] experimental evidence exists to enable an equivalent [illegible] quartz crystal [illegible] circuit having electrical [illegible] of the particular crystal used. [illegible] modification dependent on the manner in which [illegible] to the axes of the mother crystal.

[illegible] represented by the network of Fig. 1. [illegible] expressed in terms of mechanical dimensions of a crystal [illegible] the crystal axes are parallel to the [illegible] of the mother crystal can be represented with considerable [illegible] formulae:

K [illegible] farads

K [illegible] farads

L [illegible] henries

where [illegible] crystal dimensions in centimetres along the mechanical, [illegible] axes respectively.

Although [illegible] formula for the resistance R, the practical [illegible] the measured resistance is dependent on the method [illegible] varies between wide limits. The curve representing [illegible] is shown in Fig. 1a. It will be observed that the [illegible] termed the series resonant frequency, and infinite [illegible] resonant frequency, the magnitudes of which are [illegible] the difference between these two frequencies [illegible] series resonant frequency and is independent of the [illegible]

Now [illegible] crystal mounted between plates the same size as the crystal [illegible] any stray fields external to the crystal that may [illegible] between the plates. With a centrally disposed crystal there will be two small air gaps between [illegible] of the plates; these may be represented in a network as

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BEFORE discussing the bridge circuit generally used with quartz resonators, the equivalent electrical circuits associated with the quartz crystal itself will be considered. Sufficient experimental evidence exists to enable an equivalent network to be substituted for the quartz crystal in any circuit, having electrical dimensions dependent on the mechanical dimensions of the particular crystal used. The electrical dimensions are subject to modification dependent on the manner in which the crystal has been cut with respect to the axes of the mother crystal.

A piezo-electric quartz crystal may be represented by the network of Fig. 1. The electrical dimensions expressed in terms of mechanical dimensions of a crystal for Curie or perpendicular cut (i.e., a cut in which the crystal axes are parallel to the electrical and optical axes of the mother crystal) can be represented with considerable accuracy by the following formulæ :—

$$K_1 = 0.402\ 10^{-12} \frac{l_m\ l_o}{l_e} \text{ farads}$$

$$K = 0.289\ 10^{-14} \frac{l_m\ l_o}{l_e} \text{ farads}$$

$$L = 118.2 \frac{l_m\ l_e}{l_o} \text{ henries}$$

where l_m, l_o, l_e represent crystal dimensions in centimetres along the mechanical, optical and electrical axes respectively.

Although some authorities give a formula for the resistance R, the practical value of this is doubtful, since the measured resistance is dependent on the method of mounting adopted and can vary between wide limits. The curve representing reactance of the crystal network is shown in Fig. 1B. It will be observed that the reactance is zero at a frequency f_1, termed the series resonant frequency, and infinite at a frequency f_2, the parallel resonant frequency, the magnitudes of which are given in the figure. It may be noted that the difference between these two frequencies is a constant times the series resonant frequency and is independent of the dimensions l_o and l_e.

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$$K = 4.02 \times 10^{-13} \frac{l_m l_o}{l_e} \text{ farads}$$

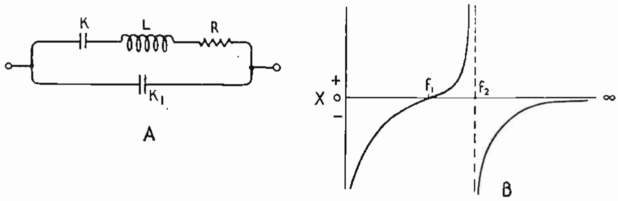
$$K = 0.0284 \times 10^{-13} \frac{l_m l_o}{l_e} \text{ farads}$$

$$L = 118.2 \frac{l_m l_e}{l_o} \text{ henries}$$

where l_m, l_o, l_e represent crystal dimensions in centimetres along the mechanical, optical and electrical axes respectively.

Although some authorities give a formula for the resistance R, the practical value of this is doubtful since the measured resistance is dependent on the method of mounting adopted and can vary between wide limits. The curve representing reactance of the crystal network is shown in Fig. 1B. It will be observed that the reactance is zero at a frequency f_1 termed the series resonant frequency, and infinite at a frequency f_2, the parallel resonant frequency, the magnitudes of which are given in the figure. It may be noted that the difference between these two frequencies is a constant times the series resonant frequency and is independent of the dimensions l_o and l_e.

Next consider a crystal mounted between plates the same size as the crystal faces and for the moment disregard any stray fields external to the crystal that may exist between the plates. With a centrally disposed crystal there will be two small air gaps between its faces and the plates; these may be represented in a network as two small air dielectric condensers either side of the network of Fig. 1, or by a single condenser K_2 having a dielectric equal to the total air gap as shown in Fig. 2A; a typical reactance curve for such a circuit is shown in Fig. 2B. It will be seen that the reactance is now zero at some frequency f_3 higher than f_1 by an amount dependent on K_2. f_3 is now the series resonant frequency of the network. It will be observed that f_2 is unaltered by capacity due to the air gap.



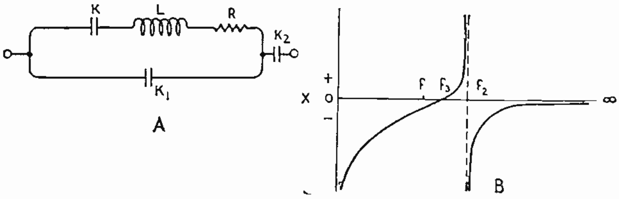
$$f_1 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LK}} = \frac{{\cdot}272}{l_m} \cdot 10^6 \text{ cycles}$$

$$f_2 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L.\dfrac{KK_1}{K+K_1}}} \text{ cycles}$$

$$f_2 - f_1 = \frac{f_1}{2} \cdot \frac{K}{K_1} = \frac{978}{l_m} \text{ cycles}$$

FIG. 1.

Finally, consider the crystal mounted between plates larger than itself having terminals or leads attached. The effect of such a mounting is to introduce a capacity shunting the network of Fig. 2 and may be represented by K_3 in Fig. 3A. From the reactance diagram it will be seen that the series resonant frequency remains the same as for the previous case, but the parallel resonant frequency is now reduced to f_4 by the action of the condenser K_3.



$$f_3 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L \cdot \dfrac{K(K_1+K_2)}{K+(K_1+K_2)}}} \text{ cycles}$$

$$f_2 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L.\dfrac{K K_1}{K+K_1}}} \text{ cycles}$$

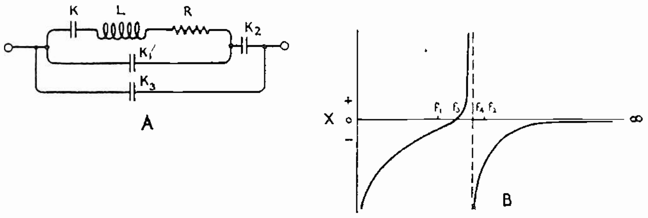
$$f_3 - f_1 = \frac{f_1}{2} \cdot \frac{K}{K_1+K_2} \text{ cycles}$$

$$f_2 - f_3 = \frac{f_1}{2} \cdot \frac{K}{K_1} \cdot \frac{K_2}{K_1+K_2} \text{ cycles}$$

FIG. 2.

Two factors therefore operate to reduce the difference between what may be termed the "natural" series and parallel resonant frequencies f_1 and f_2 of a piezo-electric quartz resonator, since an increase in the air gap results in a series resonant frequency higher than f_1 and an increase in holder capacity results in a parallel resonant frequency lower than f_2. As an example, in a 450 kC. resonator $f_2 - f_1 = 1620$ cycles, but when mounted in a holder of appreciable capacity with relatively large air gaps, $f_4 - f_3$ may be as small as 70 cycles. It will be appreciated that such a small frequency difference must result in a very steep reactance curve near the resonant frequencies.

Alteration of the crystal characteristics by alterations to the mount is an unsatisfactory method of attaining this end, apart from the limited variation obtainable. The well known crystal bridge, as used in the Stenode Radiostat circuit by Dr. J. Robinson, provides a simple and practical means of obtaining considerable variation of the characteristic. Such a bridge is shown in Fig. 4 coupled to the tuned anode circuit of a valve; the output from the bridge is coupled to another tuned circuit, auto transformer fashion. The bridge itself may be represented by the network of Fig. 5A. In what follows it will be assumed that the voltages induced in the two arms of the bridge are equal. In practice, the input inductance is generally tapped near to one end so that a relatively large balance condenser C_B (say 10 $\mu\mu f$. max.) may be used, operating well away from its minimum value. Referring to the figure, two equal voltages e, e, the phases of which are indicated, give rise to currents I_1, I_2 in the two halves of the bridge. The current through the diagonal is then $I = I_1 - I_2$. The bridge circuit may be further simplified since the impedance of the inductances shown is small compared with that of either the crystal or the balancing condenser C_B. The simplified circuit is shown in Fig. 5B. Since the network is in the form of a bridge, it is therefore possible to make $I = 0$ by adjusting the balancing condenser provided the quartz resonator acts as a capacity. It will be shown later that the



$$f_3 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L \cdot \dfrac{K(K_1 + K_2)}{K + (K_1 + K_2)}}} \text{ cycles, } f_4 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L \cdot \dfrac{K\left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)}{K + \left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)}}} \text{ cycles}$$

$$f_3 - f_1 = \frac{f_1}{2} \cdot \frac{K}{K_1 + K_2} \text{ cycles, } f_4 - f_3 = \frac{f_1}{2} \cdot \frac{K}{K_1 + K_2} \cdot \frac{K_2 - \dfrac{K_2 K_3}{K_2 + K_3}}{K_1 + \dfrac{K_2 K_3}{K_2 + K_3}} \text{ cycles}$$

$$f_2 - f_4 = \frac{f_1}{2} \cdot \frac{K \cdot \dfrac{K_2 K_3}{K_2 + K_3}}{K_1\left(K_1 + \dfrac{K_2 K_3}{K_2 + K_3}\right)} \text{ cycles}$$

FIG. 3.

effective capacity of the crystal is not independent of frequency, so that the condition $I = 0$ will strictly hold for only one frequency.

Owing to the simplifications made in the circuit, it is not to be expected that the analysis which follows is rigid. The results given, however, are sufficiently close to those obtained in practice to justify the assumptions made. It may be noted that the voltage output of the bridge is roughly proportional to the turns on the input inductance, the selectivity being but slightly affected by changes in this inductance: further, if the diagonal of the bridge is arranged as a tap on the final tuned circuit, the voltage output remains nearly constant for tapping ratios between $\frac{1}{8}$ and 1, while the selectivity progressively decreases. The former ratio approximates to a condition for proper loading or matching of crystal and tuned circuit.

A more rigid analysis could be made by taking into account the impedance of each branch of the circuit and using the principle of superposition, but the additional work involved hardly seems justified in view of the relative accuracy of the results obtained by the simpler method.

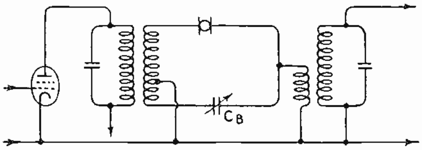
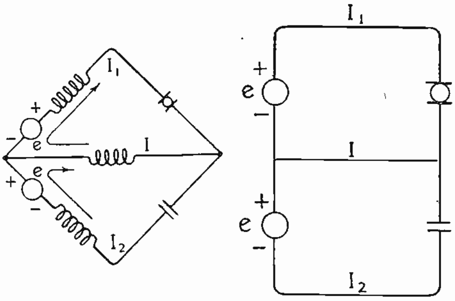


FIG. 4.

Rewriting the bridge equation

$$\begin{aligned} I &= I_1 - I_2 \\ &= e\,Y'_c - e\,Y'_b \\ &= e\,(Y'_c - Y'_b) \end{aligned}$$

where Y'_c and Y'_b represent admittances of the crystal and balancing condenser respectively. A study of the crystal network, Fig. 3, shows that its admittance is formed by the sum of the admittances of K_3 and the network of Fig. 2A. It is therefore convenient to split the capacity of the balancing condenser into two condensers in parallel, one being equal to K_3 and the other to an amount to be termed the "out of balance" capacity. If Y_C and Y_B represent the admittances of Fig. 2A and the out of balance capacity respectively, then



A. FIG. 5. B.

$$I = e\,(Y_C - Y_B)$$

$$\text{Now } Y_C = \cfrac{1}{\cfrac{R - j\,\frac{1}{wK}\,(1 - w^2 LK)}{1 + \frac{K_1}{K}\,(1 - w^2 LK) + jw\,K_1 R} - j\,\frac{1}{wK_2}} = A + jB$$

A crystal with a natural series resonant frequency of 450 kC. may have dimensions

$l_m = .605$ cm. $l_e = .3$ cm. $l_o = .4$ cm.

The corresponding electrical dimensions are then

$K = .00233\ 10^{-12} f$ $K_1 = .324\ 10^{-12} f$ $L = 53.686$ H

$R = 20{,}000$ ohms. $K_2 = 1.5\ 10^{-12} f$

The value for R given is a measured value and somewhat higher than values obtained by some authorities by calculation. As mentioned above, such calculated values are deceptive since no account is taken of damping due to method of mounting, air pressure, etc. The value of K_2 given corresponds to a total gap of .0055 ins. (.014 cm.).

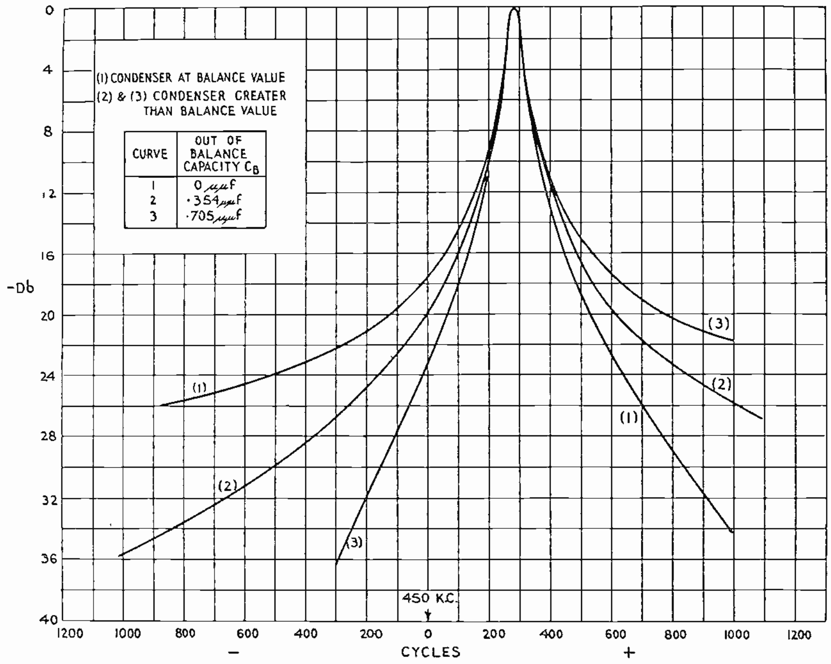


FIG. 6.

The calculation of Y_C in the form $A + jB$ is laborious, but once in this form a further j term corresponding to the amount of out of balance capacity (Y_B) may be added or subtracted according to whether the balancing condenser is set below or above the balance value. Since the admittance of a condenser of .354 $\mu\mu f$. at 450 kC. is $j\ 1\ 10^{-6}$, the calculations have been made for multiples of this value. It was thought convenient for the purposes of calculation to take the condition $Y_B = 0$ as a standard of reference, though for many purposes it might be more convenient to take that value which produces a symmetrical characteristic. Curve (1) in Figs. 6 and 9 represents this standard of reference. It will be seen that due to the gap capacity K_2 the series resonant frequency has increased above the "natural" value to 450.285 kC., while the parallel resonant frequency is 451.620 kC. This property of the gap of altering the series resonant frequency has been mentioned above. It may be noted that the series and parallel resonant peaks are approximately equal heights above and below the mean output level on a dB. scale. Another property which is not apparent from the curves, but clear from the calculations, is the increase of effective series resistance as the gap increases, for whereas the "natural" series resistance was taken at 20,000 ohms. at 450 kC., the resistance is 29,500 ohms. at the series resonant frequency of 450.285 kC. and increases rapidly as the air gap (and hence the series resonant frequency) is increased. This may easily be observed experimentally and indicates the desirability of using the minimum possible air gap for maximum sharpness of response.

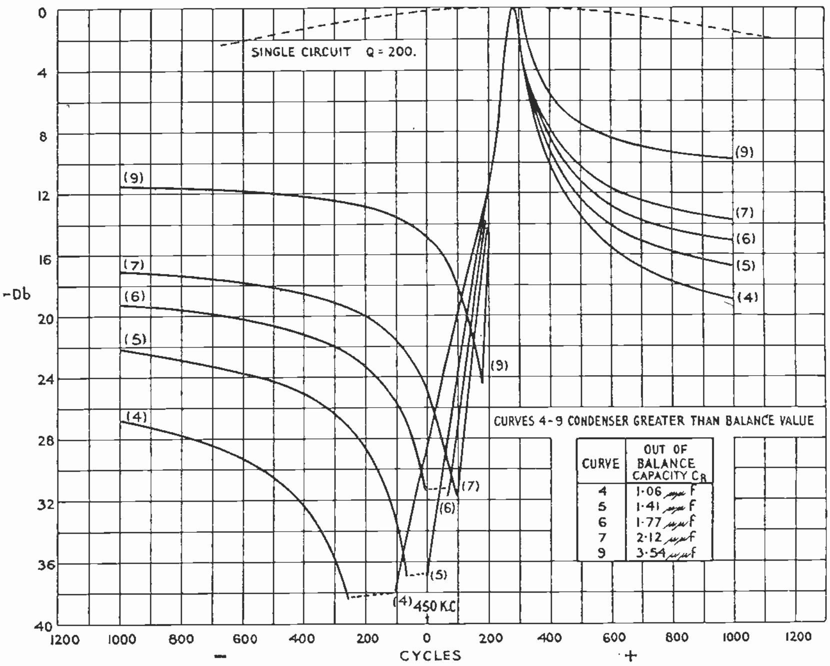

SINGLE CIRCUIT Q = 200.
-Db
0
4
8
12
16
20
24
28
32
36
40
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
CYCLES
−
+
(9)
(7)
(6)
(5)
(4)
450 KC.
CURVES 4-9 CONDENSER GREATER THAN BALANCE VALUE
CURVE | OUT OF BALANCE CAPACITY C_B
4 | 1·06 μμF
5 | 1·41 μμF
6 | 1·77 μμF
7 | 2·12 μμF
9 | 3·54 μμF

FIG. 7.

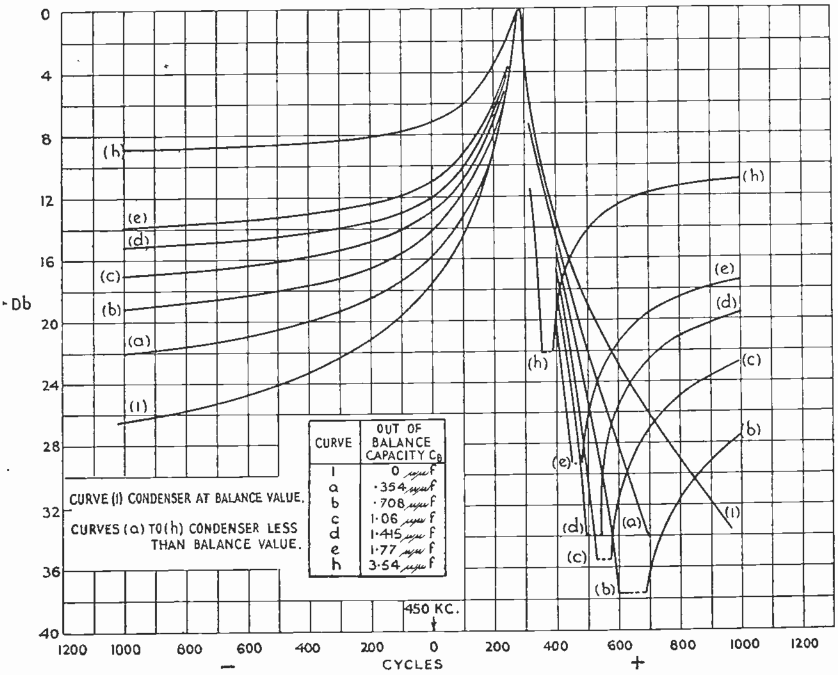

-Db
0
4
8
12
16
20
24
28
32
36
40
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
CYCLES
−
+
(h)
(e)
(d)
(c)
(b)
(a)
(1)
450 KC.
CURVE (1) CONDENSER AT BALANCE VALUE.
CURVES (a) TO (h) CONDENSER LESS THAN BALANCE VALUE.
CURVE | OUT OF BALANCE CAPACITY C_B
1 | 0 μμF
a | ·354 μμF
b | ·708 μμF
c | 1·06 μμF
d | 1·415 μμF
e | 1·77 μμF
h | 3·54 μμF

FIG. 8.

Curves (2) — (9), Figs. 6, 7 and 10, represent conditions obtaining when Y_B is positive, i.e., the capacity of the balancing condenser is greater than for the balance condition. All these curves exhibit parallel resonance at frequencies less than the series resonant frequency, whereas in curve (1) parallel resonance occurs at a frequency greater than the series resonant frequency. It might be anticipated that at some intermediate setting of the balancing condenser a symmetrical curve can be obtained. This is indeed the case. Curves D, C, B and A of Fig 11 represent gradually increasing values of the balancing condenser in this range and show that the parallel resonant frequency increases rapidly. (It should be pointed out that in the calculations the admittance of the out of balance capacity was taken as being constant over the frequency range. The error introduced by doing this is in general not more than 2 dB. and tends to make the curves less symmetrical than they actually are.) The curve of Fig. 12 represents the condition for symmetry, the condenser having a value slightly higher than that for curve A. In this case the actual admittance of the out of balance capacity was used for each frequency calculated. The curve is equivalent to that of a circuit having a Q of 7630. The curve of a circuit with a Q of 200 is shown for comparison.

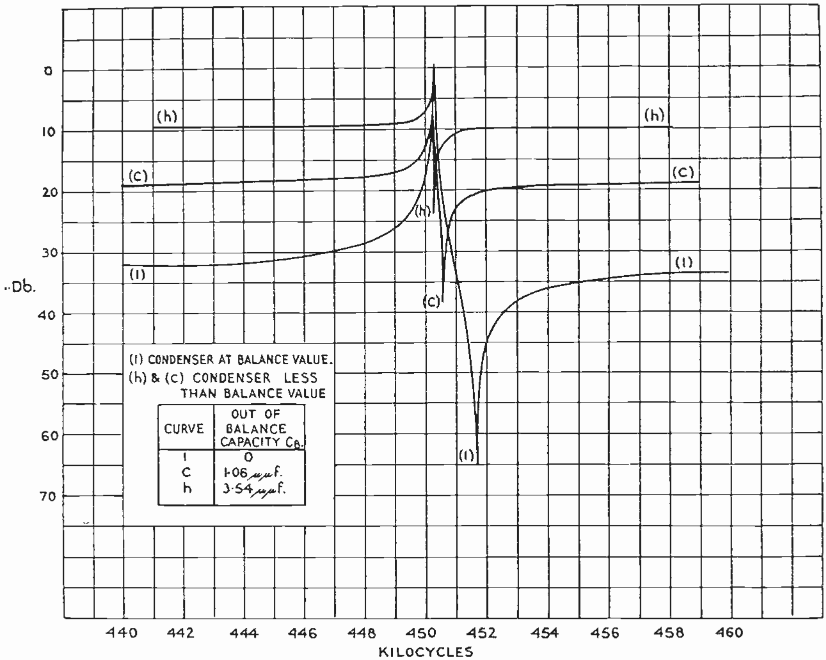


FIG. 9.

With the condenser set at less than the balance value (i.e., Y_B negative) curves (A) — (H), Fig 8, are obtained which are similar to curve (1), the parallel resonant frequency being higher than the series resonant frequency, and tending to approach the latter as the balancing capacity decreases.

In Fig. 13 is plotted the imaginary component B of Y_C from which one may visualise the manner in which the parallel resonant frequency moves from one side of the series resonant frequency to the other. The nearly vertical part of the curve is shown dotted to distinguish between series and parallel resonant frequencies.

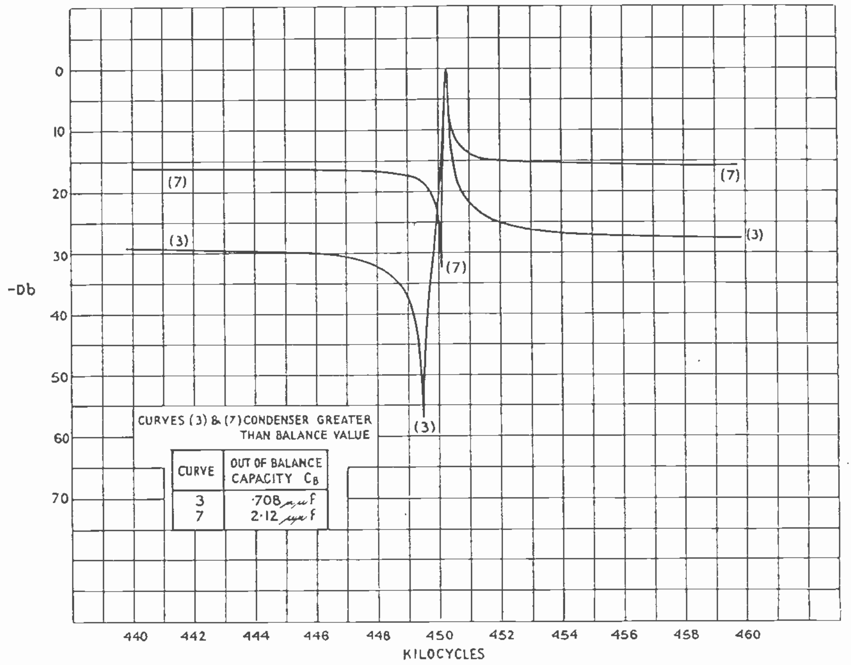

0
10
20
30
-Db
40
50
60
70
(7)
(7)
(3)
(3)
(7)
(3)
CURVES (3) & (7) CONDENSER GREATER THAN BALANCE VALUE
CURVE
OUT OF BALANCE CAPACITY C_B
3 ·708 $\mu\mu$F
7 2·12 $\mu\mu$F
440
442
444
446
448
450
452
454
456
458
460
KILOCYCLES

FIG. 10.

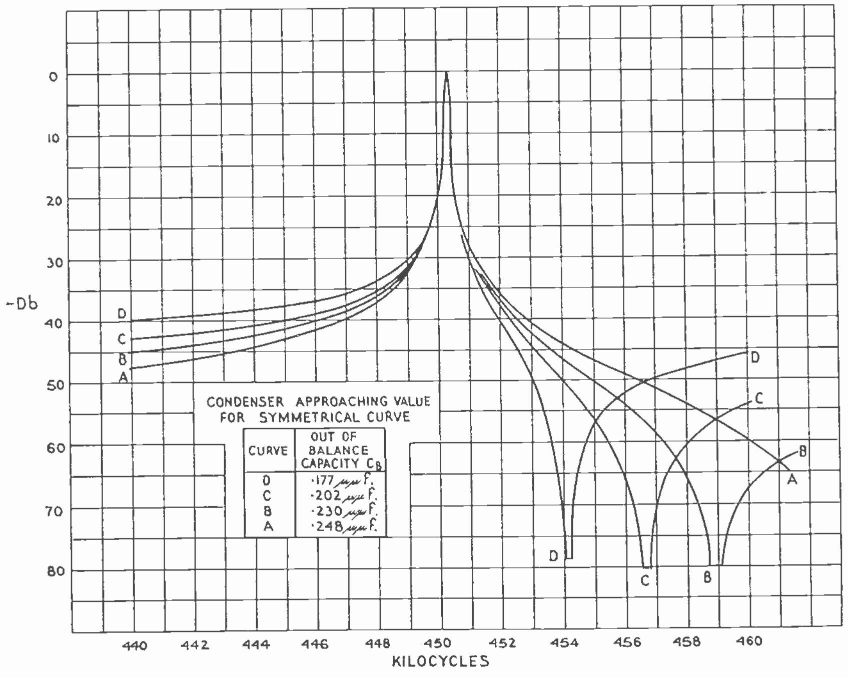

0
10
20
30
-Db
40
50
60
70
80
D
C
B
A
D
C
B
A
D
C
B
CONDENSER APPROACHING VALUE FOR SYMMETRICAL CURVE
CURVE
OUT OF BALANCE CAPACITY C_B
D ·177 $\mu\mu$F.
C ·202 $\mu\mu$F.
B ·230 $\mu\mu$F.
A ·248 $\mu\mu$F.
440
442
444
446
448
450
452
454
456
458
460
KILOCYCLES

FIG. 11.

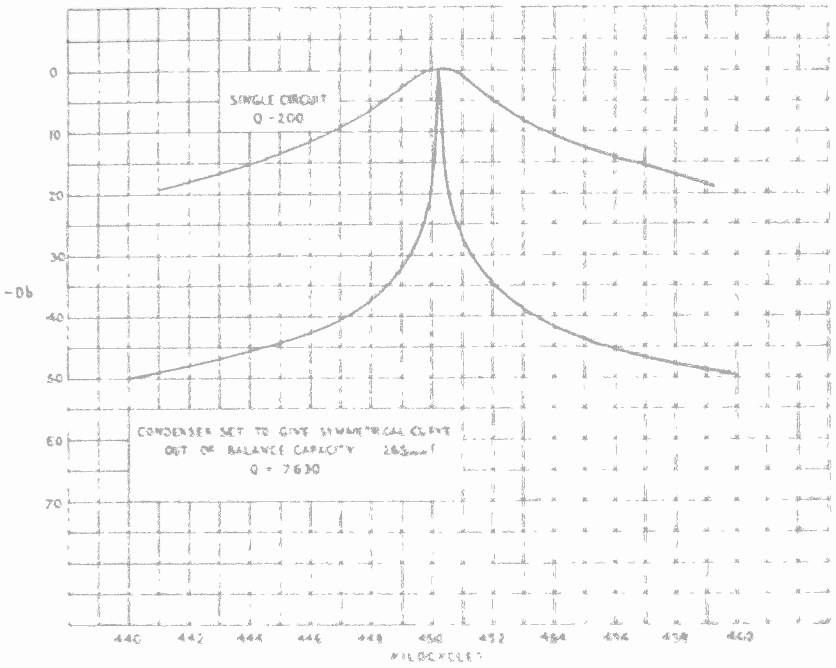

0
10
20
30
-Db
40
50
60
70
SINGLE CIRCUIT
Q - 200
CONDENSER SET TO GIVE SYMMETRICAL CURVE
OUT OF BALANCE CAPACITY 265μμf
Q = 7630
440
442
444
446
448
450
452
454
456
458
460
KILOCYCLES

FIG. 12.

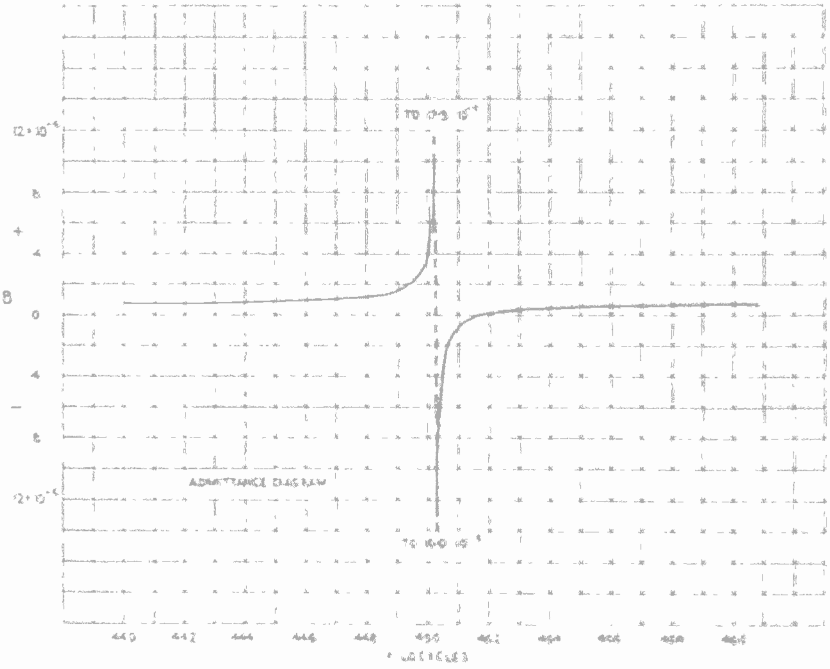

TO 100 × 10⁻⁶
12 × 10⁻⁶
8
+
4
B
0
4
—
8
12 × 10⁻⁶
ADMITTANCE DIAGRAM
TO 100 × 10⁻⁶
440
442
444
446
448
450
452
454
456
458
460
KILOCYCLES

FIG. 13.

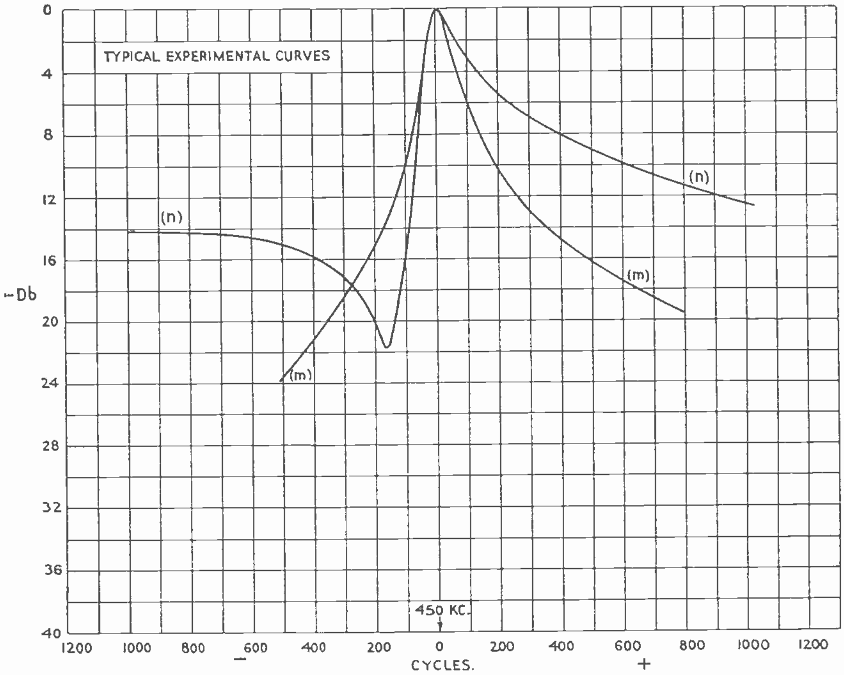

TYPICAL EXPERIMENTAL CURVES
(n)
(n)
(m)
(m)
-Db
0
4
8
12
16
20
24
28
32
36
40
450 KC.
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
CYCLES.
−
+

FIG. 14.

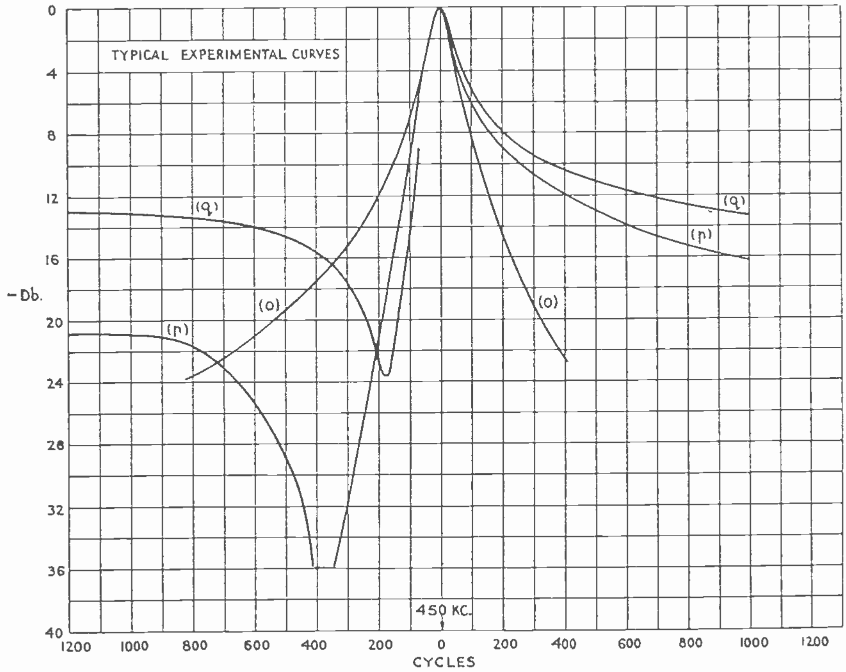

TYPICAL EXPERIMENTAL CURVES
(q)
(q)
(p)
(p)
(o)
(o)
-Db.
0
4
8
12
16
20
24
28
32
36
40
450 KC.
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
CYCLES

FIG. 15.

The dotted portion passes through zero at 450.285 kC. The out of balance capacity may be represented as a nearly horizontal line across the diagram, the line Y = O corresponding to the conditions obtaining for curve (1). Series resonance occurs at the intersection of the line with the dotted part of the curve and parallel resonance at the intersection of the line with the full part of the curve. As the capacity of the balancing condenser is increased above the reference condition, the nearly horizontal line may be moved upwards, $Y = 1 \times 10^{-6}$ at 450 kC. corresponding to an out of balance capacity of .354 $\mu\mu f$. As the line is moved slowly upwards from the reference condition Y = O, corresponding to curve (1), the parallel resonant frequency as determined by the point of intersection with the full curve increases rapidly (as in curves D, B, C, A) until the line becomes asymtotic to the curve ($Y = .75 \times 10^{-6}$). This is the condition for symmetry (Fig. 12), the parallel resonant frequency being infinite or zero. A further movement upwards results in intersection below the series resonant frequency, the parallel resonant frequency rapidly approaching the former but always less than it, as in curves (2)-(9). For settings of the balancing condenser below the balance value, the line may be moved downwards, i.e., Y negative. The parallel resonant frequency is then higher than, but tends to approach, the series resonant frequency as in curves (A) — (H). The construction described is intended to enable one to visualise the method of operation of the crystal bridge near the position of balance. It does not hold for a large amount of out of balance, i.e., near the peaks of the curve.

The curves described above relate only to the crystal bridge ; the output from the circuit of Fig. 4 closely follows these curves except that there is additional loss for frequencies off resonance depending on the selectivity of the tuned circuits. The response of an efficient circuit is shown on Fig. 12. The loss for off-tune frequencies should be added to that associated with the crystal bridge to obtain the overall curve of the complete circuit. A selection of experimental curves shown in Figs. 14 and 15 exhibit close agreement with the calculated curves. The curves represent results on two different crystals using a very small air gap, the crystal resting on one of the holder plates which were horizontal. The input frequency was adjusted for peak output, and using this value as a zero reference, points were taken every 33 cycles on either side for the first 200 cycles and thereafter every 100 cycles. The series resonant frequency was not exactly 450 kC., but only approximately this value. Curves (M) and (O), Figs. 14 and 15, represent attempts to provide symmetrical curves, and their departure from the ideal is some indication of the critical setting of the balancing condenser required for this condition.

A point of interest occurs as a result of the condition taken as a standard of reference. The condition was that all capacity external to the crystal was balanced out. The curve (1) for this condition is unsymmetrical and additional balancing capacity is necessary to produce symmetry. This additional capacity represents the inherent capacity of the crystal.

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O. E. KEALL.

MARCONI NEWS AND NOTES

NEW DEVELOPMENTS FOR AIRCRAFT WIRELESS.

A VERY interesting visit was paid last month by representatives of the British Press to the new Marconi Aircraft Wireless Establishment, at Wandle Road, Hackbridge, Surrey. This is the latest addition to the Marconi Company's already extensive organisation for the design and manufacture of aircraft installations, and we feel that a short description of the new establishment would be of interest to our readers.

As is well known, the Marconi Company has been engaged in the development, design and manufacture of wireless apparatus for aircraft since the earliest days of aviation, before the war, and by the constant application of its stores of specialised experience accumulated over the years, backed by its vast research and development organisations which are continually exploring and extending the more general branches of the wireless art, has reached complete pre-eminence in this field.

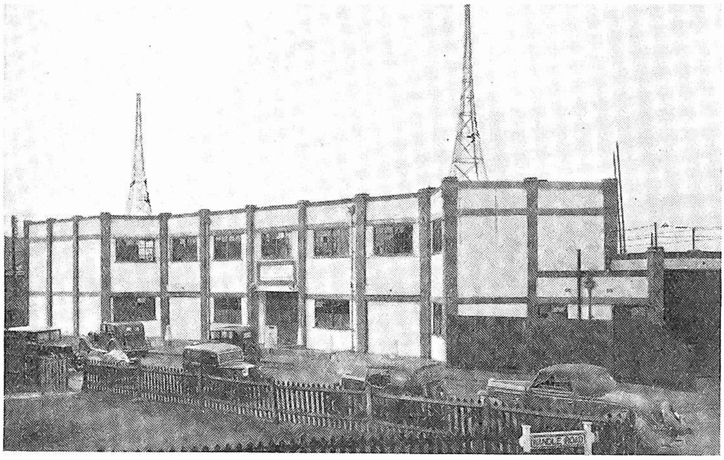
Until the opening of Hackbridge Establishment, all aircraft development was carried out in the Aircraft Development Section at the London Terminal Aerodrome, Croydon, while all manufacture was done at the famous Marconi Works at Chelmsford. The rapidly increasing demand for Marconi aircraft equipments during the last few years brought about by the rapid increase in aviation, and the recognition of the outstanding superiority and reliability of the Company's products by the organisations responsible for the operation of air transport at home and abroad, by the British Air Ministry, and by foreign governments, has made the continuation of this practice impossible, in spite of the very considerable extensions made and being made to the Chelmsford Works. The Marconi Company therefore decided to create the separate Aircraft Wireless Establishment at Hackbridge, where the development, design and manufacture of aircraft equipments could be undertaken under one roof. Hackbridge was chosen as a suitable site as it is close to the Croydon Aerodrome, and thus the close contact already established with the Air Ministry, Imperial Airways, and the other operating companies based there remains unbroken.

The Aircraft Development Section was transferred from its premises at Croydon Aerodrome and the most suitable and experienced men from the Chelmsford Works and from other branches of the Marconi Company have been selected to form the staff of the Hackbridge Establishment, and work there is now in full swing.

The Aircraft Wireless Establishment is responsible for research, development, first model design and commercial production of all new types of aircraft apparatus. All branches of the work are undertaken until the new designs are completely standardised and can therefore be passed over to the Chelmsford Works, with complete instructions and drawings for normal production. The first batches of new models are built at Hackbridge until all technical and mechanical difficulties have been overcome and the work of manufacture reduced to a matter of pure routine.

The floor space available is rather more than 6,000 square feet on two floors. The top floor is used for administration, research, development, drawing work and testing the finished products. The ground floor is occupied by the workshops, stores and packing sheds, and also the offices concerned with the planning and progressing of production.

The aircraft research engineers, who keep closely in touch with the whole of the Research and Development Departments of the Marconi Company and can, when necessary, draw on the vast store of knowledge and experience thus available, concentrate on the special problems and circuits involved and the special principles of mechanical design and manufacture required, and on new ways of applying wireless to the service of aviation. The results of this research are embodied by the development engineers in "lash-up" models which are thoroughly tested, modified and retested, until fit to be taken over by the model development section, which is then responsible for the detail design and building of the practical models. For this work highly skilled mechanics, capable of working to rough free-hand sketches and written notes, are employed, using the workshops on the ground floor. These first models are the prototypes of the final products.



General view of the exterior of the Marconi Aircraft Wireless Establishment, Hackbridge.

The first models are submitted to exhaustive bench testing and modified until ready for testing in aircraft in flight. The flight tests are carried out at Croydon Aerodrome, where the Marconi Company now uses the Development Hut, the forerunner of Hackbridge, as a flight test base, maintaining a special flight engineer for the purpose. This engineer is usually accompanied in flight by the development engineer responsible for the "lash-up" design, so that the test bench and designing experience of the development engineer is allied to the practical operational experience of the flight test engineer. The Marconi Company does not maintain its own aeroplane for this purpose, as it has been found far more satisfactory to carry out flight tests in the particular type of aircraft for which the equipment has been designed, than to test all types in the same small aircraft. Thus large equipments for passenger machines are tested in large machines, and fighter equipments in the small spaces and considerable noises experienced in fighter machines. It is thus possible to track down and overcome practical difficulties due to noise, vibration, ignition screening and bonding troubles at their source, and embody the necessary refinements before production begins.

When, and only when, research, development, first model and flight engineers are satisfied with results, is the prototype model handed over to the drawing office for detailed drawing for production purposes. On completion of the drawing work, actual production begins.

But this care in development and design is not sufficient in itself to ensure the perfection of performance and reliability in service for which the Marconi Company's aircraft products are noted. In addition, the material used in their construction is inspected, tested and checked in accordance with Air Ministry requirements from the time it enters the Establishment until the finished equipments are ready for despatch. The Marconi Company is approved by the Air Ministry for the design, manufacture and installation design of aircraft equipments, and takes every possible step to justify this approval. The rigid system of inspection and test ensures that the stringent requirements for the manufacture and release of wireless apparatus for civil aircraft under Air Navigation Directions are fully met, and makes it possible to trace back any fault in material or workmanship at any time to its origin either in material or to an individual workman.

The finished instruments and complete equipments are finally tested in the Testing Department on the first floor. To ensure that no deterioration or loss of technical efficiency is permitted in the course of normal production, the research or development engineers are always available on the spot as advisers to the Testing Staff, and are responsible for the preparation of detailed specifications, which must be rigidly adhered to by the Testing Staff. Only after several batches of equipments have been produced to the complete detailed drawings and put into service successfully, is a design considered complete and is then handed over to the Chelmsford Works for routine production.

Such centralised control of the evolution of new aircraft designs was not possible before the formation of the Hackbridge Aircraft Wireless Establishment, so we may now expect future Marconi aircraft products to be even better, if possible, than those already on the market.

Space is not available here to describe in detail some of the new designs now in hand at Hackbridge, but a few can be mentioned here. Work is very advanced on the new AD57/58 equipment which is being produced for the big fleet of flying boats at present being built by Short Bros., at Rochester, and land planes by Armstrong Whitworth, Ltd., for the new Imperial Airways Empire and Transatlantic services. A full description of this equipment will be published in a subsequent issue of the MARCONI REVIEW.

Work is also nearing completion on the Marconi ultra-short wave aerodrome approach and landing equipments, the first models of which are to be installed at Croydon and Gatwick aerodromes. The receivers for use with these ground stations are also well under way.

A new fighter equipment, the type AD63/64 is in hand, as are also many other equipments and designs not yet ready for production, but which will, we hope, further enhance the Marconi Company's prestige in the field of aircraft wireless, and be of great service to aviation.