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As many of the circuits and apparatus described in these pages are covered by patents, readers are advised, before making use of them, to satisfy themselves that they would not be infringing patents.

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EDITORIAL COMMENT

Television

America Takes the Plunge

IN an address to the Radio Manufacturers' Association in New York a few days ago, Mr. David Sarnoff, President of the Radio Corporation of America, propounded his views on television and announced the intention of the Radio Corporation of America to start a limited programme service to the public from its television transmitter on the Empire State Building in New York.

Mr. Sarnoff stated that the results of the experimental field tests of television in the New York area conducted by the R.C.A. and its broadcasting and manufacturing units, had convinced him that television in the home was "now technically feasible." That television in the home was technically feasible would, we should have thought, have been obvious to Mr. Sarnoff for a very long time, in view of the position on this side; but, nevertheless, it is interesting to have his assurance that in America, too, they are satisfied with the technical success of the tests they have carried out.

An Experimental Service

Next, Mr. Sarnoff admits that many technical, artistic and financial problems still confront "those who would establish an acceptable and regular service of television to the home" and that these problems must be solved before a "national service of a network of television programmes can be made available to the public." He has also come to the conclusion that "the problems confronting this difficult and complicated art can be solved only by operating experience gained by actually serving the public in their home." This, we believe, represents a change in the attitude hitherto adopted towards television in America, where it has generally been implied that retaining television in the laboratory was favoured until it was so perfected that it could be launched to the public on a big scale.

Small Beginnings

The R.C.A. proposes to demonstrate television to the public at the New York World's Fair in April, 1939, and by that time the National Broadcasting Company hopes to be transmitting television programmes "for at least two hours a week." The R.C.A. is ready to build and supply television transmitters to broadcasting authorities and believes that development of television has now reached a stage where receivers can be supplied to the public in those localities where transmitters become available. A manufacturing programme for a limited number of receivers is therefore planned. Other manufacturers in the United States are also arranging to produce television receivers.

England has had the lead in television for a number of years and those who have been involved in development on the technical side and on the programmes have worked hard and productively towards the goal of establishing a new national service and a new national industry. There are still problems to be solved and the two which loom largest are unquestionably those of nation-wide distribution of television and financing the transmitting project as a whole. We in this country have not yet found the solutions to these major problems, and if we placidly wait for "something to turn up," America, which will soon be faced with the same difficulties, may well find the answers first. If so, we shall soon find her forging ahead of us.

Crystal Band-Pass Filters

Part I.—QUARTZ CRYSTALS AND THEIR CHARACTERISTICS

By E. L. GARDINER, B.Sc.

THE applications of quartz crystals have recently been greatly extended by the development of band-pass circuits in which they form essential elements. These filters have very desirable properties and offer advantages not only in broadcast receivers but in communication sets and commercial equipment. In this series of articles, the properties of such filters will be described in detail and the subject is started by a discussion of the properties of the crystals themselves.

IN *The Wireless World* of September 15th, 1938, appeared a preliminary description of a new type of band-pass filter developed by Dr. James Robinson in which a pair of quartz-crystal resonators is used to determine the width of the pass-band. Filters of this kind have many attractive properties, which include a very sharp cut-off and readily adjustable characteristics, and which make them very suitable for use in communication or broadcast receivers. They are singularly simple to design and construct, whilst their cost may be less than that of conventional filters having comparable performance. They have also a variety of commercial applications, of which carrier - current telegraphy and telephony are examples. The present writer has carried out much of the experimental work on crystal filters that has been going on since the invention of the single crystal filter, or "crystal gate," by Dr. Robinson in 1929, and in these articles will describe the performance to be expected from them and the methods by which they may be designed.

The Single Crystal Circuit

It was shown in the preliminary article how the combination of two single crystal filters can lead to a band-pass characteristic, and that effect will not be enlarged upon for the moment. We shall study it in detail later, after a selection of performance figures has been given. However, since the crystal band-pass filter has been largely evolved from the single crystal variety, it will be helpful to recall some of the properties of the latter. The "crystal gate" is now so widely used in the better class of communication receivers that it will be familiar to most readers, and particularly to those who hold amateur transmitting licences. It is generally regarded as the most selective device available for the reception of CW telegraph signals, and is used to a lesser extent for telephony, but it is probably not so widely known that the circuit was originally evolved for the reception of broadcasting.

About 1929 the selectivity of receivers left much to be desired, and it was seldom possible to separate the more powerful signals without considerable loss of the higher modulation frequencies, which resulted in rather "woolly" reproduction. Except, perhaps, in a few advanced technical circles the distinction between band-pass and single-peaked tuning was but vaguely understood, it being generally thought impossible to employ really high selectivity in a broadcast receiver without loss of quality. About this time Dr. Robinson brought forward his "Stenode" theory of reception, which stated that signals could be received through any circuit, however selective, and that the original tone quality could be restored after detection by increased audio-frequency amplification of the higher tones, or any equivalent form of correction. When this was done he showed that the interfering programmes after removal by the selective circuits would not be restored by tone correction.

General technical opinion at that time held that all interference would be restored after correction, leaving no overall improvement, and considerable controversy ensued. Eventually, however, the "Stenode" theory was proved to be sound, and is now universally accepted. In practice, it has been found to result in an improved ratio of signal to interference as compared with practical band-pass filters, an effect not originally expected, but explainable through the effects of detector demodulation. A sharply selective response reduces all neighbouring carriers in relation to that of the wanted station, which is therefore much stronger at the detector. In consequence it is able largely to demodulate the weaker carriers, and since interfering modulations have thus been removed, they cannot be restored by tone correction. An exhaustive investigation organised by the Radio Research Board in 1932[1] finally established the soundness of these principles.

The high selectivity required for Stenode reception is not easily obtained from ordinary circuits. It is either necessary to employ a number of these in cascade, when tone correction is not a linear function and is difficult to carry out, or else to rely upon critical reaction, when circuit conditions are not easily stabilised. The quartz crystal was introduced to overcome these difficulties. Used as a coupling between two IF stages it provides high selectivity in a single resonator, which is the condition most easily tone-corrected by audio-frequency amplification increasing proportionally to frequency.

Under practical conditions it at once became apparent that the self-capacity of the crystal holder could not be neglected, but allowed appreciable interfering voltages to by-pass the crystal. A bridge circuit of the type shown in Fig. 1 was therefore adopted, in which the unwanted capacity coupling can be neutralised by the condenser C. The adjustment of this condenser enables us to obtain a symmetrical resonance curve from the crystal, corresponding to that of a resonator of extremely high "Q," as was explained in the preliminary article. By varying the adjustment of C we can also assist one side band of a transmission and depress the other, obtaining in the extreme case an attenuation of as much as 80 db. at one frequency where the voltage through the condenser is almost equal and opposite in phase to that through the crystal. This effect is widely used to cut out an interfering signal when receiving telegraphic signals through a "crystal gate."

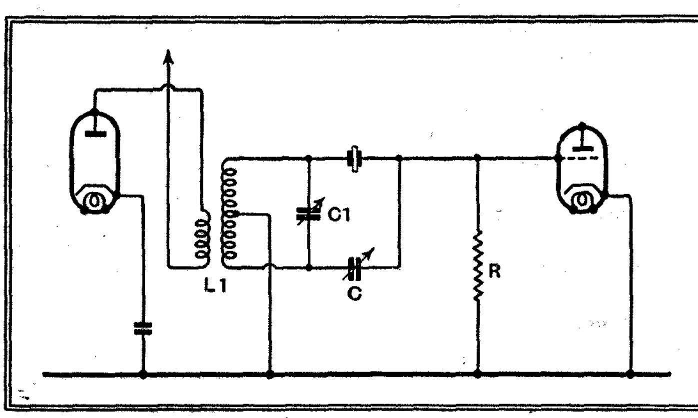


Fig. 1. This diagram shows the usual circuit arrangement for a single quartz crystal. It is widely used for CW reception.

Broadcast receivers employing the crystal as the chief source of selectivity

[1] Special Report No. 12, by F. M. Colbrook, 1932.

Crystal Band-Pass Filters—

were designed in 1930, giving excellent results in the laboratory, and providing a ratio of signal to interference probably better than can be obtained by any other method. In only a few cases, however, have commercial receivers made full use of the principle, since certain difficulties were found to exist, and were not easily overcome with the components and methods available in the past.

As an example, the sharpness of tuning needed to get signals into resonance with the crystal and keep them so made adjustment very difficult for the average listener, and is only now being finally overcome through the development of automatic tuning compensation. Secondly, the relatively low amplification given by early valves prevented adequate tone correction without increased cost, and it was necessary to await new methods such as negative feed-back before simple correction without attendant drawbacks became practicable. It is only in quite recent months that most of these difficulties have become less important, suggesting the likelihood of increased use of the Stenode principle in future receivers.

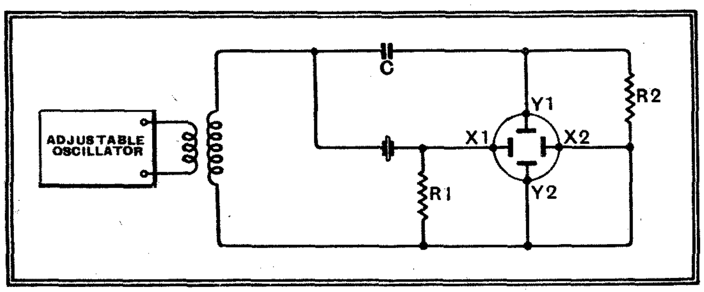


Fig. 2. This circuit is recommended for testing quartz crystals for secondary resonances.

Crystal Characteristics

Meanwhile, an alternative method of design exists in the band-pass filter, and one which, while not capable of quite such high selectivity, has the advantage that its use does not complicate a receiver in any other respect. Up to the present it has not been easy to obtain good band-pass performance without the use of a number of circuits, and difficulty has been found in keeping all these lined up throughout the life of a receiver. The quartz crystal, however, seems to provide a method for improving filter performance, at quite reasonable cost, and with an actual simplification of the circuits used, while the selectivity will remain almost unchanged over the longest periods. Variable selectivity can, in addition, be very simply provided by the switching in of one or two alternative crystals, a single pole switch being adequate for the whole alteration.

In introducing the study of such filters it will be natural to commence with the crystals themselves, and to enquire whether they are obtainable in suitable form, whether they are satisfactory, and not prohibitive in cost.

Early in experimental work it became clear that insufficient was known about crystal design, and about the equally important matter of their mounting in suitable holders. Even when a single crystal is employed in a "crystal gate" it may be necessary to take some trouble in its selection, but when it is attempted to combine two or more crystals into a band-pass filter, it is clearly essential that they shall be suitably matched, and shall remain so from day to day. The crystal itself is, of course, a highly stable and reliable device, but unfortunately it cannot be used without a holder, and the latter may be responsible for a good deal of variation in performance. Moreover, all crystals are not necessarily suitable for use in filters.

For a number of years quartz resonators have been mainly used to stabilise the frequency of transmitters. The main requirements of a crystal for this work are that it shall be accurately ground to the desired frequency, shall remain as near to that frequency as possible under changes of temperature, shall oscillate readily and shall handle considerable RF power without fracture. Development has therefore been mainly concentrated along the lines of great frequency accuracy and a low temperature coefficient, neither of which is necessarily of first importance in filter design for radio purposes. Transmitting crystals are generally expected to remain accurate to within a few cycles per second, but we can usually tolerate a variation of as much as 1 kc/s in the intermediate frequency of a receiver. They are also made comparatively large, so that the crystal can pass considerable RF current in safety, and will not become unduly hot under oscillating conditions. This provision will not be necessary when the crystal is used in a receiving filter, since it then has to handle very small currents only. In fact, a large crystal may actually prove inferior to smaller types.

On the other hand, there are certain properties needed in a filter crystal which are not important in one intended as an oscillator. Foremost amongst these is freedom from secondary resonant frequencies near to the main frequency. The frequency of a crystal depends, of course, upon its dimensions, and there are always at least two frequencies at which it can be made to respond, and which depend upon two of its principal measurements. There may also be other frequencies, including harmonics or "partials" of the main response frequencies, but the whole of these alternatives are well removed from the main response, and the crystal can be prevented from operating at them by the use of external selective circuits. Thus, for example, if a crystal be ground to a main frequency of 465 kc/s, it will also respond to certain higher frequencies, but none of these will lie within 100 kc/s of 465 kc/s. The ordinary tuned couplings of an IF amplifier can easily eliminate signals so far removed from resonance, and we are therefore quite justified in ignoring their existence in the majority of circumstances.

Secondary Resonances

The troublesome secondary frequencies referred to are those which may occur within a few kilocycles of the principal frequency. They are probably due to slight inaccuracies in the cutting of the crystal, or to lack of uniformity in the quartz from which it is made. It would be outside the scope of this article to describe in detail the cutting of crystals from the natural quartz. The subject is a wide one, and fully explained in a number of text-books and several other publications.[1]

However, high-frequency crystals are generally prepared in the form of thin plates, their principal frequency being determined by the thickness of the plate. Most transmitting crystals are of this form. Now, clearly, the whole surface of this plate will only respond at the same frequency if the thickness be exactly uniform. Should any portion of the plate be slightly thicker or thinner, it will tend to respond at a slightly lower or higher frequency, and may impart a secondary response to the crystal. Also it is likely to reduce the activity of the crystal at its principal frequency, because the total area active at that frequency has been reduced.

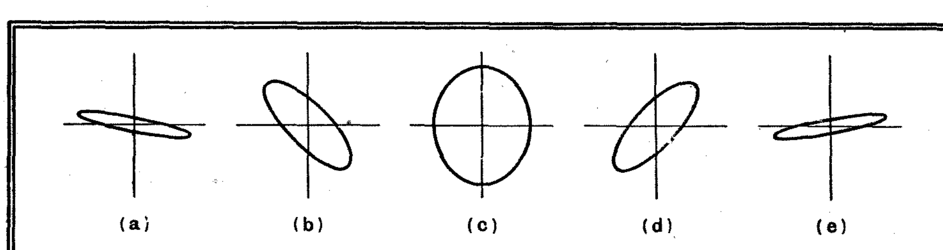


Fig. 3. As the frequency of the test oscillator is varied through the crystal resonance the pattern on the CR tube screen varies smoothly as shown here. At (a) the oscillator is considerably below the crystal frequency and at (b) it is approaching resonance which is reached at (c). At (d) the oscillator is a little higher than resonance and at (e) it is much higher.

It is very difficult in practice to prepare large thin plates of exactly uniform thickness from quartz, and as a result most transmitting crystals of that form show serious secondary responses which make them unsuitable for filter work. Many receiving crystals were first made in this

[1] "Quartz Crystals and Resonators," P. G. Vigeseux, H.M. Stationery Office.

Crystal Band-Pass Filters—

way, and as a rule were unsatisfactory. Until very recently the writer had not encountered a single example which was entirely free from secondaries when tested under exacting conditions, although most would be quite satisfactory when used as oscillators, since a crystal will generally oscillate freely only at its principal resonant frequency. American crystals found in communication receivers are often still of this type, and some of those met with to-day show no measurable secondaries. Nevertheless they should be tested carefully before use in band-pass filters. It is doubtful in any case whether their characteristics are ideal for the purpose, as will be shown later.

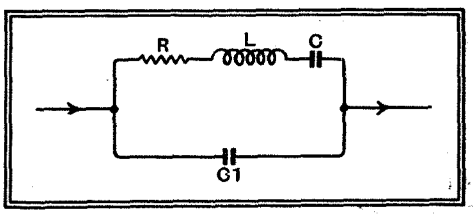


Fig. 4. This diagram shows the equivalent electrical circuit of a quartz crystal. L, C, and R form the series tuned circuit, resonance in which corresponds to the crystal resonance, while C1 represents the capacity of the crystal holder.

A very sensitive method exists by which a crystal can be tested for secondary responses. Voltage from an oscillator at the principal frequency is applied through a condenser C which serves as an amplitude control to one pair of plates of an electrostatically deflected cathode-ray tube. The same voltage is passed through the crystal to the second pair of plates, as shown in Fig 2. The resistances R1 and R2 should be comparatively low, as this assists in minimising stray potential through the capacity of the crystal holder, which must not be too great. Upon the screen of the tube will now appear an ellipse, which is the figure produced by two similar voltages of identical frequency but differing somewhat in phase. Now, the phase of the voltage through a crystal varies rapidly on each side of its resonant frequency. If, therefore, the frequency of the oscillator be slowly varied from about 20 kc/s below to 20 kc/s above resonance, the ellipse will change from nearly a horizontal straight line, opening out as resonance is approached and the voltage through the crystal increases, to become nearly a circle at resonance. Since there is some loss of voltage in the crystal, however, it will probably become merely an open ellipse, having its principal axis perpendicular to the original straight line, or vertical in the case described. Passing beyond resonance, the process is repeated, the ellipse reverting to a horizontal line in the opposite direction. Fig. 3 shows sketches of the change which occurs.

In the absence of secondary responses the above process will be uniform and smoothly carried out, but if we should pass through a secondary response frequency there will be a momentary disturbance of the phase relationship. The slope of the major axis of the ellipse measures the angular phase difference between the voltage applied to the crystal and that passing through it at any instant. Therefore a momentary change of phase will be shown as a discontinuity in the even rotation of the ellipse, which will twitch or shudder as the secondary frequency is passed. The phase changes caused by a secondary are greater than those of amplitude, and thus the method shows up defects which would need very careful search to detect if the output through the crystal were measured by a voltmeter, for example. Under receiving conditions these quite small secondaries might be serious, since they may coincide with the frequency of a very powerful interfering station, and it is important that they should be absent from a really good crystal.

Crystal resonators are also cut in the form of relatively long rectangular bars, in which the principal frequency is determined by their length; 100 kc/s frequency standards are usually of this form, which lends itself well to frequencies between about 1,000 kc/s and 50 kc/s or below. It is therefore suitable for the most widely used intermediate frequencies, which we shall take as being 465 kc/s. A bar-type crystal is more easily cut to exact dimensions, since small errors represent a much smaller proportion of the total length. It is found that if certain ratios of length to breadth and width are adhered to, crystals can be made which are inherently free from secondaries, and it has been found that considerably less than 1 per cent. of those so prepared show defects. They are, therefore, very suitable to filter design.

The Crystal Impedance

The original form of crystal-cut developed by Currie and termed the "X-cut" is effective, comparatively simple to prepare, and makes the most economical use of the available quartz. When it is employed, the resonator is cut from the natural crystal so that its major surface is perpendicular to the electrical axis of the crystal, and one other dimension is parallel to the optical axis. The resulting slice, when cut to exact dimensions, is loosely termed "a crystal." X-cut bars have a moderately large temperature coefficient, of perhaps six parts in a million per degree centigrade. Smaller coefficients can be obtained in transmitting crystals by cutting obliquely to the optical axis, but for any ordinary filter purpose the coefficient mentioned is amply satisfactory.

In one other respect the shape and size of a crystal have an important influence. They determine the effective values of L, C and R in the equivalent circuit of Fig. 4, and hence the impedance to which the crystal falls at resonance. Broadly speaking, the impedance of all crystals will be extremely high at a few kilocycles from resonance, usually exceeding one megohm. At resonance it will fall to a value very roughly proportional to the mass of quartz forming the crystal. Thus large crystals may fall to a few thousand ohms, or even below 1,000 ohms, while a small crystal may fall to some figure such as 20,000 ohms. We can therefore speak broadly of high impedance and low impedance crystals.

Plate-type crystals have low values of impedance, and the sudden large drop at resonance gives the impression that they are extremely "active." For certain applications, such as a single crystal filter having suitably designed input and output transformers, these crystals may be excellent. The small X-cut bar might seem inferior if used in the same circuit, in which conditions have been chosen to match a low crystal impedance. But the coupling circuits between valves are inherently of fairly high impedance, the anode load of a typical RF stage being usually between the limits of 10,000 and 100,000 ohms. It is therefore natural to employ high impedance coupling circuits between valves, and any change to a low impedance, such as by the use of large step-down transformer ratios, is likely to reduce efficiency. The high impedance crystal is therefore admirably suited for use in band-pass inter-valve filters, in which the impedance matching must in any case be chosen to match the crystal, as will be explained in a later article.

We have now selected a small X-cut bar as one very suitable type for use in band-pass filters. This crystal may have an effective Q of the order of 20,000, and may represent an impedance of between 5,000 and 15,000 ohms at resonance. It can be of almost any frequency, but so as to confine our remarks at present to a useful range and enable definite statements to be made, we will assume it to be near 465 kc/s. Unfortunately this crystal cannot be used alone, but must be inserted into a holder of some kind. The electrical capacity of this holder can be compensated for by the balancing condenser C of Fig. 1; but there will be other effects caused by the holder which are less simply treated.

RADIO LABORATORY HANDBOOK

By M. G. Scroggie, B.Sc., A.M.I.E.E.
(The Wireless World, 8s. 6d.)

**Here's a book for young and older
By a quite unusual bloke,
Who can think, and write, and solder,
And who likes his little joke.**

**He twits the academical,
The cultured folk like we,
Who take no care financical.
(But we do, as much as he!)**

**There's guidance without stinting
For the handy wireless man.
Good pictures, index, printing.
You should buy it if you can.**

* * *

**When you're up against it, flabber-
Gasted, puzzled, sick and foggy,
Do not rage or moan or blabber;
Take a chair and read your Scroggie.**

L. B. T.

The above has been received from a reader, and we hope he will not take exception to its publication for the benefit of all who care to enjoy it.

How a Receiver is Designed.—XXIX.

All-wave Battery Set

CONSTRUCTION AND ADJUSTMENT

MOST details of the mechanical aspects of the receiver can be gleaned from the drawings and photographs and there is little which requires explanation. The gang condenser is not mounted directly on the tuner chassis, however, but is slightly spaced from it. Three bolts are placed through the chassis from the underside and nuts run-on and tightened on top. The condenser is then placed over the bolts and further nuts used to secure it. In this way the condenser is spaced from the chassis by the thickness of one nut. This spacing is adopted in order to make it easier to reach the solder-tags of the fixed plates with a soldering iron.

When wiring the tuner it is advisable to connect the lengths of wire to the tags for the moving arms of the switches before the switches are mounted. When the switches are in place these tags are rather inaccessible with an ordinary iron. The connections to the gang condenser are then best completed and afterwards the valveholder wiring, the coils and other switch leads being left to the last.

Some surprise may be felt at the general mechanical arrangement of the receiver, for it would undoubtedly have led to a somewhat simpler lay-out and wiring if all components were on a single chassis. On short waves, however, a flexible mounting of the whole of the tuning equipment is very desirable if microphony is to be reduced to a minimum. The flexible mounting of the gang condenser alone does not always give such satisfactory results.

With a unit construction for the tuner, which incidentally also leads to good screening, it is necessary for the main chassis to consist of two sections so that the tuner can be slung between them. With a large receiver the construction often takes the form of a large and rigid chassis with a cut-out for the tuner. In this case, there is no justification for this course, and the main chassis consequently takes the form of two narrow chassis joined together at back and front by cross-strips.

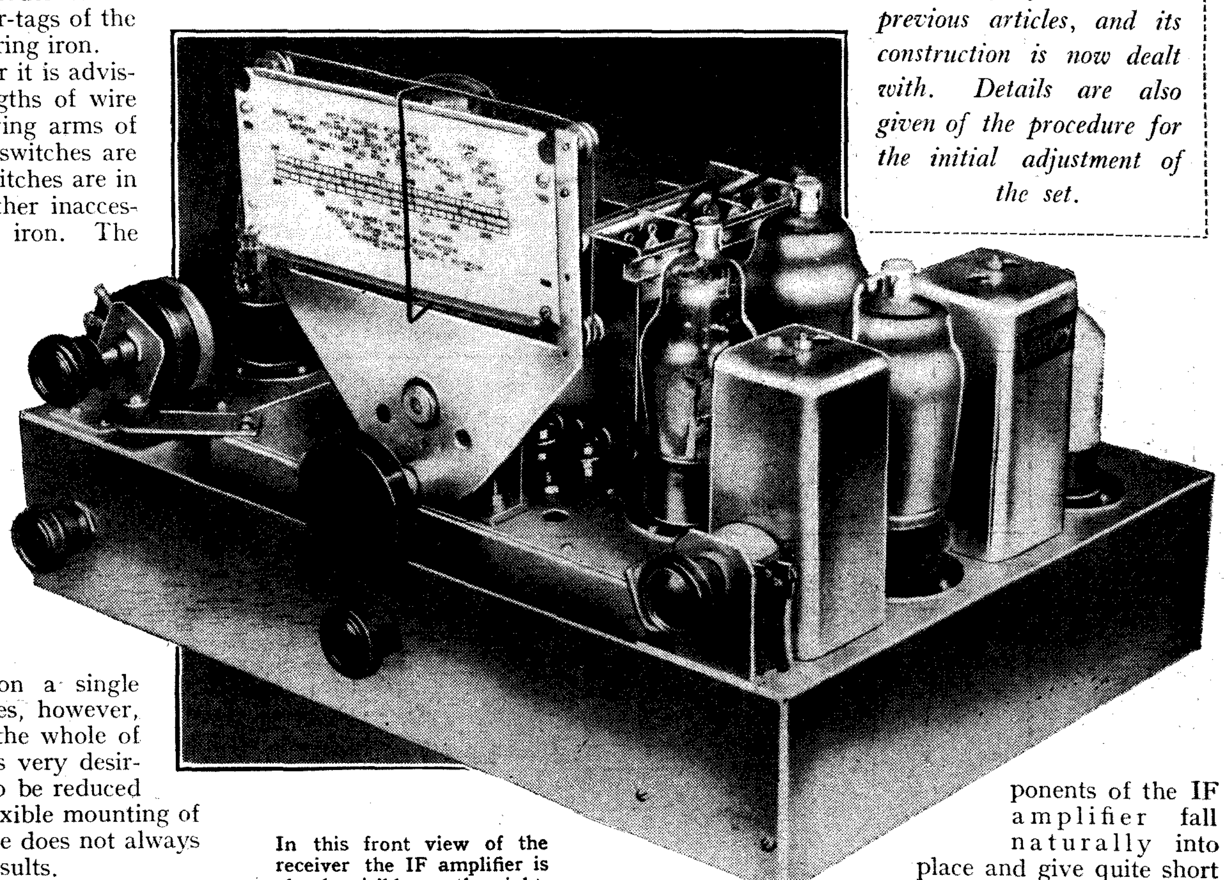
In the tuner the layout of components has been chosen primarily for electrical reasons. The gang condenser is immediately above the switches so that the leads between them can be as short as possible, and the valves are placed as close to the gang condenser as they can be in order to keep the grid leads short. Incidentally, it was mechanical considerations which led to the choice of the Tungsram VP2D for the RF stage, for the valve is one of the few battery RF pentodes with a top-grid connection.

It is instructive to consider what changes would be needed to accommodate a top-anode type of valve and how it would fall short of the requirements. In the first place, the valveholder would have to be moved into the aerial-coil compartment, and in the second the anode connection to the valve would have to run from the top of the valve to the primary switch in the middle compartment. This lead would be at least six inches long and it would almost certainly be necessary to screen it. This would cause little trouble on medium and long waves, but on short waves the extra capacity of the screening would be harmful. The use of a top-grid valve is a distinct advantage in reducing the length of leads.

In the case of apparatus which lies outside the tuner the length of leads is of much less importance because of the lower frequencies at which the circuits operate. Care has been taken, nevertheless, to get the first IF transformer as close as possible to the frequency-changer valve for experience shows that a long anode lead to such a valve can be a cause of parasitic oscillation. Trouble of this nature is, of course, much less likely to occur with battery valves than with mains types on account of their lower efficiency. It is considered advisable, however, not to run any avoidable risks.

THE theoretical considerations underlying the design of this receiver have been fully discussed in previous articles, and its construction is now dealt with. Details are also given of the procedure for the initial adjustment of the set.

With the construction adopted the components of the IF amplifier fall naturally into place and give quite short leads. The only really long connections are those between the detector and AF amplifier, and they are unimportant at this point because screening can be used without harmful effect.

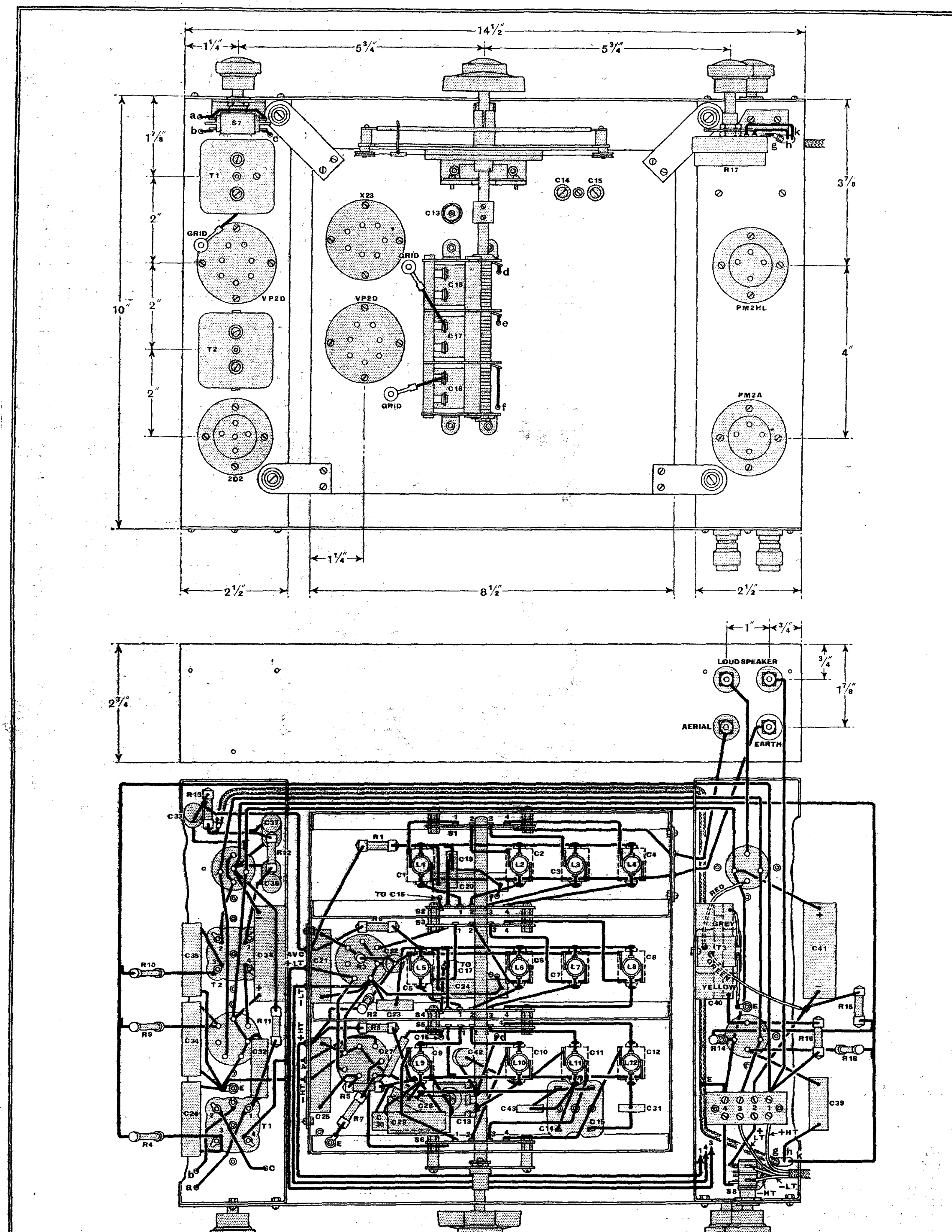


In this front view of the receiver the IF amplifier is clearly visible on the right.

Turning now to operation and adjustment. The receiver is designed to operate with an HT supply of 120 volts, but a higher voltage can be used with some advantage if the higher current is tolerated. At 120 volts the total current consumption is about 14 mA., so that it is advisable to use a medium- or large-capacity battery. The LT supply should be an accumulator as the current is 0.9 ampere at 2 volts. A capacity of some 20 A.h. is advisable.

The loud speaker is not unimportant, for

ALL-WAVE BATTERY SET—ASSEMBLY AND WIRING DETAILS



Full-size blueprint of the above wiring diagram is available from the Publishers, Dorset House, Stamford Street, London, S.E.1. Price, 1s. 6d., post free.