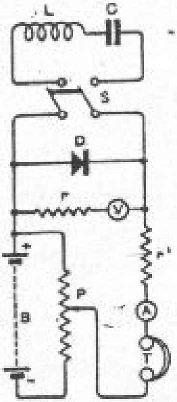

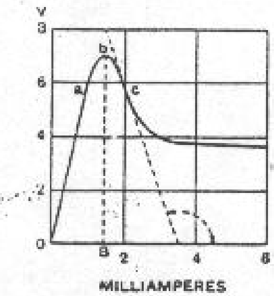

Fig. 1. Circuit for testing the aptitude of different crystals for generating or amplifying. Fig. 2. Characteristic curve of a suitable specimen of crystal.

THE CRYSTAL AS A GENERATOR AND AMPLIFIER.

By Victor Gabel.

THE first account published in English of the work of the Russian engineer, O. Lossev, in producing oscillation and amplification by means of crystals, appeared in *The Wireless World and Radio Review* of July 11th last, and since then references have been made to the same subject in other journals, both in this country and in America, but no additional information has been disclosed.

In this issue we have pleasure in giving publication to a further article, contributed by an engineer in Russia who is closely in touch with the work done by Mr. Lossev and others in that country. This article discloses all that has so far been recorded by way of observations on the action of the crystal and methods are given for testing crystals for oscillating properties, whilst in addition practical details are supplied on how to prepare crystals for the purpose. In addition, the author supplies a number of circuits and explains their operation so that the experimenter is provided with definite data to work upon in investigating further these extraordinarily interesting properties of the crystal.

APART from the immense possibilities which this epoch-making discovery of a new application of the crystal foreshadows, the experiments now being conducted may lead to some light being thrown on the theory of operation of the crystal during the process of detecting, a subject which is not yet fully understood. The pioneer work in these experiments is due to a Russian engineer, O. Lossev, and the following theories, which are the result of his experiments, may serve as a guide to those experimenters who are sufficiently interested to pursue the subject.

Selecting the Crystals.

It has been found that the best and most consistent results are obtainable when a zincite crystal is used in conjunction with a carbon contact, the oscillations once produced, remaining very stable and continuing without readjustment for indefinitely long periods, although the initial adjustment of the contact is rather more critical than is usual for ordinary detecting. The combination using a steel point also works satisfactorily. A copper contact used with zincite gives very poor results, whilst aluminium contacts are still less satisfactory.

The results obtained with other crystals, including galena, pyrites, carborundum and molybdenite, were very inconsistent, all of them oscillating badly or giving no results at all. It was found possible to obtain oscillations with the ordinary coherer, and even with a microphone contact, but they were very unstable.

Circuit for Testing the Crystal.

The following observations relate exclusively to zincite with carbon or steel points in contact. In order to understand the physical causes and the conditions necessary for the generation of oscillations with a detector contact, it is necessary to be acquainted with the characteristic of the crystal contact. The diagram, Fig. 1, shows how this curve can be obtained. The detector which is under test, is shown at *D*, whilst a galvanometer *A* measures the strength of the current which passes through the detector. A resistance r of about 100,000 ohms is for voltage measurement in conjunction with a galvanometer *V*, r^1 being a resistance of 1,000 to 5,000 ohms, and *B* a battery across which is shunted a potentiometer *P*, which should have a resistance of approximately 800 ohms. The inductance and capacity of the oscillating circuit into which the detector may be introduced by means of the switch *S*, are represented by *L* and *C* respectively. Employing this circuit, it is possible to determine the aptitude of different crystals for generating and amplifying.

It is, of course, well known that only certain points of a crystal are suitable for detecting and these must always be found by experiment. The same may be said concerning generating, for not only are oscillations only produced when contact is made with certain suitable points, but it is impossible to obtain even a compromise elsewhere. It might be thought that generating and detecting points would coincide, but in general, such is not the case, the circumstances favouring the production of oscillation not necessarily agreeing with those needed for efficient detecting.

Assuming that it is desired to find the generating point on a really sensitive crystal utilising the circuit shown in Fig. 1, it is necessary first to close the switch *S* and to adjust the potentiometer so that from about 6 to 12 volts is placed on the detector. By searching the different points on the crystal with the contact wire, the generating point will be found when a note is heard in the telephones. If the note remains pure and steady and does not change in tone during an interval of one minute, it is an indication that the point is a sensitive one. By cutting out the switch *S*, it will be possible to obtain the characteristic of the detector, showing graphically the relation between the applied potential and the current.

In order to obtain plotting points for the curve, the applied voltage is regulated through the agency of the potentiometer, commencing from zero and noting at each change on *A* the value of the current i, and on *V* the voltage. After reaching a current reading of about 5 to 6 milliamperes the measurements obtained can be marked on squared paper after the manner shown in Fig. 2. The current values are marked off along the axis of the abscissa, and the voltage along the axis of the ordinate. The resultant characteristic provides not only the direct corelation of *V* and i but also enables the detector to be regarded as a conductor possessing changing resistance properties.

By referring to the characteristic illustrated, it will be observed that the resistance between the points *O* and *a* remains approximately the same, after which it diminishes and becomes zero, when the current is equal to *O B*, whilst after the point *B*, for instance, at *C*, the resistance becomes negative. As a physical quantity, negative resistance has no significance, but the expression is accepted in mathematical physics where negative resistance is introduced as an algebraical quantity. It will, of course, be appreciated that the steeper the slope of the curve, the greater will be the change of resistance value. In view of this it may be assumed that the resistance of the generating point to weak currents is high and positive, after which it diminishes to zero and then becomes negative, the negative value increasing up to a certain point, after which it gradually diminishes again, as the curve shows.

If the current i passing through the detector is at first weak and then gradually increases, the detector will at first act as an ordinary positive resistance, that is to say, it will absorb the energy equal to i^2R. This will continue until the current passes over the point *B*, after which the absorption of the energy is equal to $i^2 (-R)$ or $i^2 R$ will become negative. When this state of affairs is reached, the energy will no longer be absorbed, but will, on the contrary, be returned or added to the output, so that the detector becomes a source of energy. In the event of an alternating current being present in the oscillating circuit *LC* (Fig. 1) whilst the potential is adjusted on the detector contact so that the detector works on the steep portion of the characteristic, then the detector commences to amplify the oscillations in *LC*, maintaining and increasing the oscillating current.

This effect can, obviously, only be produced when the detector is operating upon the negative portion of the curve. Thus, by suitably adjusting the applied potential, it is possible to attain such a state of balance that on the one hand the received oscillations are amplified, and on the other the amplified oscillations take place partly in the position of the negative and partly the positive resistance, when a simultaneous operation of amplifying and detecting can be obtained with the same crystal.

Practical Details for Heating the Zincite.

In the case of a bad specimen of zincite, the crystal may be greatly improved by being fused in an arc. This is best accomplished by placing the crystal on a carbon or iron

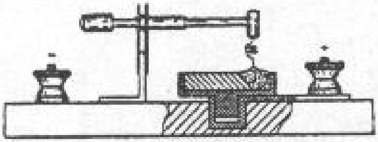

Fig. 3. A simple type of detector suitable for giving good adjustment.

plate, and sprinkling it with manganese dioxide. An arc is formed between the crystal and the carbon electrode, the process being watched through a dark glass. When the crystal is fused into an oval mass it is left to cool, after which the non-conducting crust which will be found to have formed on the surface, is cleaned off and the crystal is mounted into a cup with fusible metal in the usual way. The resistance of a crystal after being prepared in this manner is reduced about seven times.

The Crystal Holder.

For the convenience of the operator, it is advisable to pay special attention to the construction of the detector holder. A type recommended is that shown in Fig. 3. The contact wire, which should be twisted at the top into a spiral of about two turns, with a diameter of approximately 7 mm., should be made of hard steel not larger than No. 34 S.W.G. The crystal should be mounted in a cup the inner diameter of the cup being such that when the crystal is placed near the edge, and the cup rotated, fresh points of contact will be brought opposite the steel wire. It should be noted that the crystal is connected to the positive pole of the battery and the wire to the negative. As it is essential that the detector be protected from vibration, it would be advisable to place a rubber or cloth pad under it. When searching for the generating point the contact wire should not be pressed too hard upon the crystal.

Explanation of the Action of a Crystal Detector.

It is known that conductors possessing a negative resistance are generally able to self-oscillate. Chief among such conductors the arc, possessing a characteristic greatly resembling that of the detector, calls for special attention. The similarity of the two characteristics gives rise to the thought that the action taking place in the arc, and at the contact of the detector, must be similar in physical respects. Experiments and tests carried out by the author have partly corroborated this theory. As early as 1921 Hoffman surmised that the rectifying action of the detector might be explained by electronic discharges arising in consequence of a high gradient of potential at the point of contact. The formation of the arc may be represented as in Fig. 4, where a section of a contact greatly enlarged is shown.

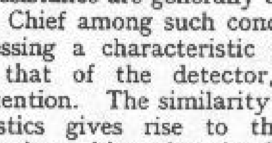

Fig. 4. An enlarged section of an arc, and it is suggested that the action of a crystal detector is due to an electron discharge, in some respects having similar properties.

As the surface of the crystal is always rough, it might happen that the end of the wire or the carbon might make contact on a sharp projection of the crystal adjoining a depression. Due to the fact that the ohmic resistance at the point of contact is very high, whereas the difference between the contact wire and the neighbouring points of the crystal is small, there may arise, if the current be strong enough, such high gradients of potential that electron discharges become possible. This suggestion is roughly outlined in Fig. 4. These discharges, although resembling the arc, differ from the latter in that the electrodes are not incandescent. For the formation of an arc the electrodes must be made red-hot either through previous mutual contact or through a discharge at high pressure. For the arc this "puncturing pressure" is about a hundred times higher than that needed for its maintenance.

The Effect of Temperature on Crystal Adjustment.

Experiments show that this relation in a zincite detector is between two and three. The difference may be explained by two causes—(1) the contact point is heated by virtue of its resistance to a temperature sufficient for a high potential to be unnecessary for a discharge to take place, or (2) the conditions favouring the discharge of electrons are different at such small distances. In experiments undertaken with the object of investigating this matter the generating contact was heated by means of a wire spiral heated by a current, the spiral being placed at a distance of one millimetre over the surface of the crystal. The results proved that the contact is very sensitive to changes of temperature, and a generating point found at normal temperature lost its properties when the spiral reached dull red heat.

A further result of these tests, however, was of considerable importance, for it was found that sensitive points discovered on the crystal when the spiral was at dull red heat possessed, under normal temperatures, a very high maximum voltage. At the same time the characteristic no longer indicated a negative resistance, and it became flatter and considerably lower, whilst the voltage, which corresponds to the highest point of the characteristic (point *B*, Fig. 2) fell much lower. Different characteristics taken at different degrees of heating showed in general that even small variations of temperature seriously affected the shape of the curves.

With one sample of zincite it was noticed that a current of 6 milliamperes was sufficient to make the characteristic lose its peak, which reappeared, however, after a time if the detector was not subjected to the influence of the current. This extreme sensitiveness to changes of temperature tends to confirm the suggestion previously made as to the difference in the conditions of the formation of the arc and the electron discharge of the crystal detector. The arc has a temperature of about 3,000 deg., whereas in the case under discussion it would seem that the action takes place at a temperature of not more than 100 deg.

There is, of course, the possibility that the electrodes of the detector may become heated by the action of the applied current. This observation suggests that care should be exercised when searching for a generating point to avoid passing an excessive current through the detector, as much time might be lost in a fruitless search under altered conditions. A current of 8 to 10 milliamperes can heat the points of contact to such an extent that the whole nature of the crystal may undergo a change.

Working the Crystal Contacts in a Vacuum.

In any event, such an overheated point would completely lose its property as a generator. It seems probable that, if the whole detector were placed in a high vacuum to prevent any of the electron energy being dissipated in air, the electron flow, and at the same time the oscillation energy, might be amplified.

[The concluding instalment of this important article, appearing in the next issue, will give numerous practical circuit arrangements.]

THE CRYSTAL AS A GENERATOR AND AMPLIFIER.

By Victor Gabel.

(*Concluded from page 5 of previous issue*).

Oscillating Crystal Circuits.

THE circuit of a generator was given in *The Wireless World and Radio Review* of June 11th, No. 252, page 300, but it is reproduced again in Fig. 5 for convenience of reference.

A circuit in which oscillations of audible frequency are produced is represented by C_1 and L_2. If the switch S is set in the upper position and the telephones donned, a generating point on the crystal may be found by trial. After the oscillations have commenced the switch may be thrown into the lower position, when oscillations of high frequency will be obtained. It is of importance that the switch should contain a dead contact in the centre (as shown on the diagram), for otherwise the oscillations may cease during the process of switching over.

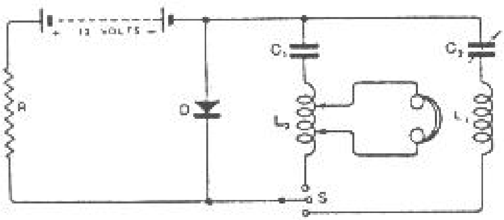

Fig. 6. Circuit for setting up oscillations.

It will be seen that the circuit also contains a resistance R in the direct current lead. The purpose of the resistance, which is indispensable in all circuits with generating crystals, is as follows. Let it be assumed that a milliammeter of low resistance has been included in the circuit Fig. 1 instead of a galvanometer with a resistance r^1 as shown; in other words, that the battery is applied directly to the detector.

Under these circumstances the contact would always be at the potential applied from the potentiometer, and it would thus be impossible to obtain a negative characteristic. The presence of resistance allows a free change of the potential applied to the detector, therefore the sum of the voltages at D and R (Fig. 5) must be constant, the potential difference at D changing in accordance with the strength of the current, it being always adjusted by corresponding changes of the voltages on the ends of the resistance.

Experiments have shown that R must always be higher than the average negative resistance of the detector, which is usually no higher than 900 ohms. The minimum value of R, therefore, is about 1,000 ohms. In order to choke back the oscillations from passing through to the battery circuit, it is desirable that the resistance should possess an inductance. For this purpose it is advisable to wind R (Fig. 5) of thin copper wire on an iron core. It is, of course, possible to include a separate choke coil of such a resistance that with the resistance R the total does not considerably exceed 1,000 to 1,500 ohms. The resistance of the inductance L_2 should also not exceed 50 ohms.

The following conditions found by means of experiments must be approximately fulfilled in order to be certain that high frequency oscillations will commence when the switch is brought over to the lower position :—

$$R_2 = R_1 \text{ and } \frac{L_1}{L_2} = \frac{C_2}{C_1}$$

where R_2, L_2 and C_1 are the resistance, the inductance and the capacity respectively of the audio-frequency circuit and R_1, L_1 and C_2 are the resistance inductance and capacity of the high frequency circuit.

Referring to Fig. 6, a circuit useful for obtaining very short waves, it was found that the oscillating energy might be considerably increased by including a condenser C_3 in parallel with the generating detector D. For short waves of the order of 200 metres, 0·002 mfds. capacity was found a suitable value, 0·004 mfds. suiting waves between 200 and 2,000 metres. A further advantage of including this condenser is that the purity of the oscillations obtained is considerably

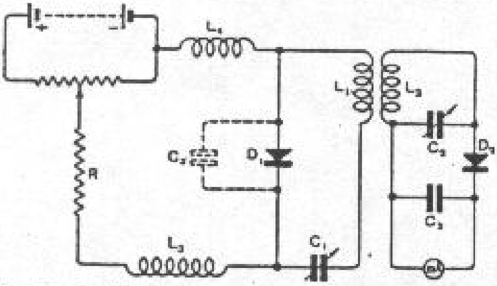

Fig. 6. Oscillating crystal circuit. C_2 is introduced and increases the amplitude on short wavelengths.

increased. Where waves of over 2,000 metres are being dealt with, the condenser becomes no longer necessary. Fig. 7 shows a complete circuit for a C.W. receiver.

In view of the previous remarks the operation of the circuit should be easy to follow. the low resistance telephones. Should the telephones possess a resistance of 50 ohms or lower they may with advantage be included in the oscillating circuit instead of across the coil L_1.

The inductance L_2 is wound with copper wire not finer than 24 S.W.G. It consists of 220 turns wound on a former of 12 centimetres diameter with a length of 10 centimetres. Such a circuit is suitable for reception on wavelengths of from 2,000 to 15,000 metres. A circuit in which a zincite detector serves simultaneously as a generator of continuous waves and as a detector is shown in Fig. 8. By means of the potentiometer P it is possible to adjust the operation of the crystal in such a manner that it can work, as has been previously explained, on a point of the characteristic where it detects and where simultaneously its resistance becomes practically equal to the resistance of the antenna.

The note of spark and telephony stations will not be affected in any way, but only

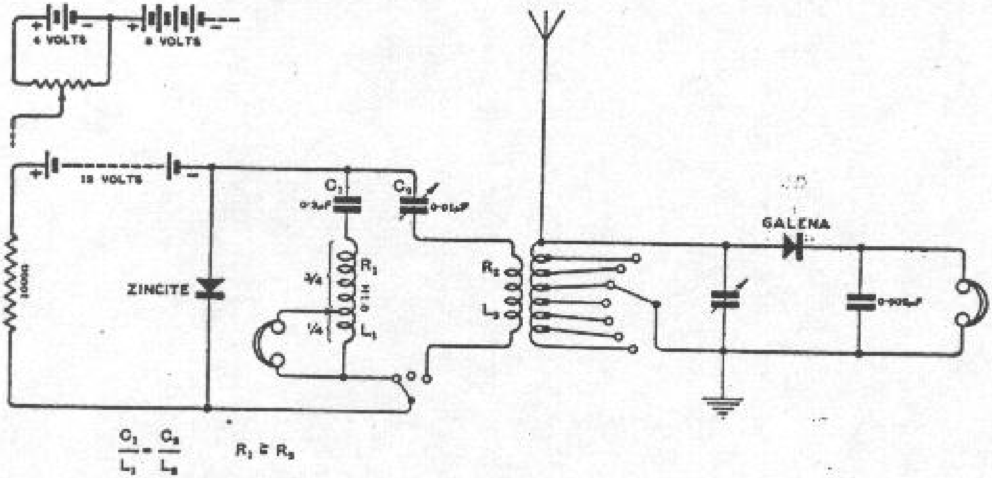

Fig. 7. Receiving circuit for C.W. reception, using a crystal oscillator for heterodyning the incoming oscillations.

The value of the heterodyne battery should be 12 volts, the current being about 3 milliamperes. For convenience the last 4 to 5 volts may be controlled through the agency of a potentiometer having a resistance of about 400 ohms. The coil L_1 having an inductance value of 0·1 henry and a resistance of 50 ohms is preferably wound with 28 S.W.G. copper wire, a section of about a quarter of the turns being shunted by amplified, the operation being similar to that of a valve amplifier with reaction.

It may be noticed that the frequency of the oscillations generated by the crystal, changes slightly with the adjustment of the potential through the potentiometer.

Waves shorter than 1,000 metres are received, using the circuit shown in Fig. 9. In this circuit the condenser C serves for increasing the oscillation energy, its capacity being about 0·004 mfds. In the circuit of a receiver shown by Fig. 10 the telephone receivers serve simultaneously for discovering the generating point by means of the oscillating circuit and for the reception of C.W. This dual use is accomplished by means of the double-pole switch *S*. Placed in the left-hand position it brings the telephones into the low frequency circuit L_2, C_2, and when connected to the right-hand contacts the telephones serve for the reception of the oscillations of the antenna. This

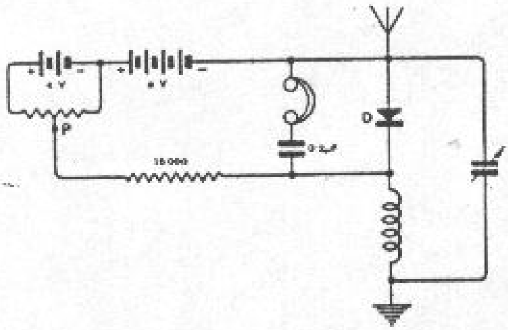

Fig. 8. Regenerative crystal receiving circuit for long wave reception.

switch must also be provided with a dead contact in the centre. The choice of the values of the inductances and capacities must depend on the same considerations as have been dealt with above.

A zincite detector can also be made to serve as an efficient amplifier. It has already been seen in the circuit of Fig. 8 that it is possible to obtain an amplifying process by means of a crystal, in a similar manner to a valve amplifier using reaction. It is, however, possible to arrange such a circuit when the

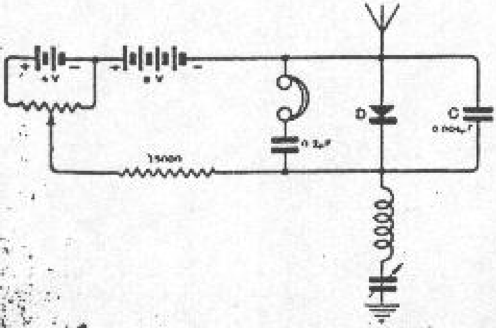

Fig. 9. Short wave regenerative crystal receiver.

detector itself amplifies the energy received in the antenna. Figs. 11, 12 and 13 are examples of such circuits.

An amplifier comprising a high frequency circuit C_1, L_1, which serves as a tuner and

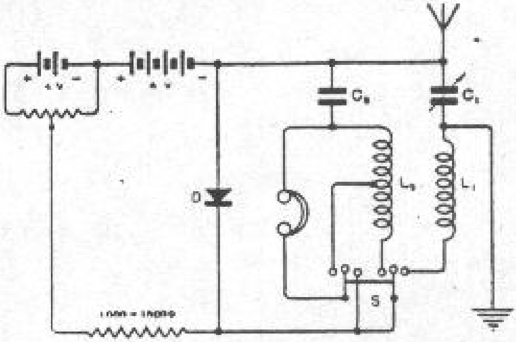

Fig. 10. A switch is here introduced so that the crystal can be adjusted to an oscillating condition.

a low frequency circuit L_2, C_2, is shown in Fig. 11. In order to operate the amplifier successfully the potential applied to the crystal must be high enough to get the

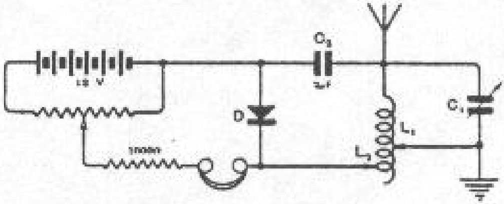

Fig. 11. Another regenerative circuit.

detector almost to a generating state, but generating must not commence, because the circuit produces oscillations of audio-frequency. A crystal can detect and at the

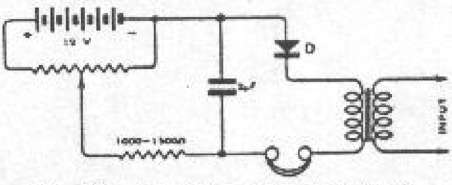

Fig. 12. An L.F. amplifying circuit.

same time produce amplification. A 15 to 1 amplification is even possible if the potentiometer is so adjusted as to keep the rise and fall of the oscillations of the circuit C_2, L_2, in phase with the received oscillations.

A low frequency amplifier is shown in Fig. 12, which, however, gives only a low amplification factor.

The last, Fig. 13, represents the circuit of an amplifier working independently. It will be seen that the zincite detector-amplifier is connected straight on to the aerial. The receiver is used with an ordinary detector D_2, C L being the tuner.

In all instances where the detector is used as a generator or amplifier it is advisable to use telephones of low resistance of between 100 to 250 ohms.

Using some of the circuits described, it has been possible to achieve transmission over a distance of one mile. On both sides the crystal served simultaneously as a generator and detector, so that even duplex transmission was possible.

This new sphere for the use of a crystal opens up a wide field for investigations of great scientific value, and it is a matter in which both the amateur and advanced experimenter can participate. It may be mentioned that any practical

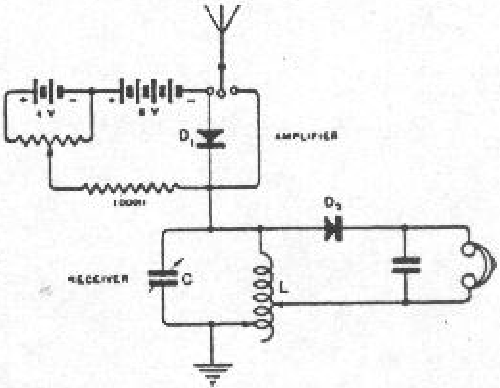

Fig. 13. Another oscillation amplifying circuit.

developments produced would be of extreme interest to those who are at present working along these lines.