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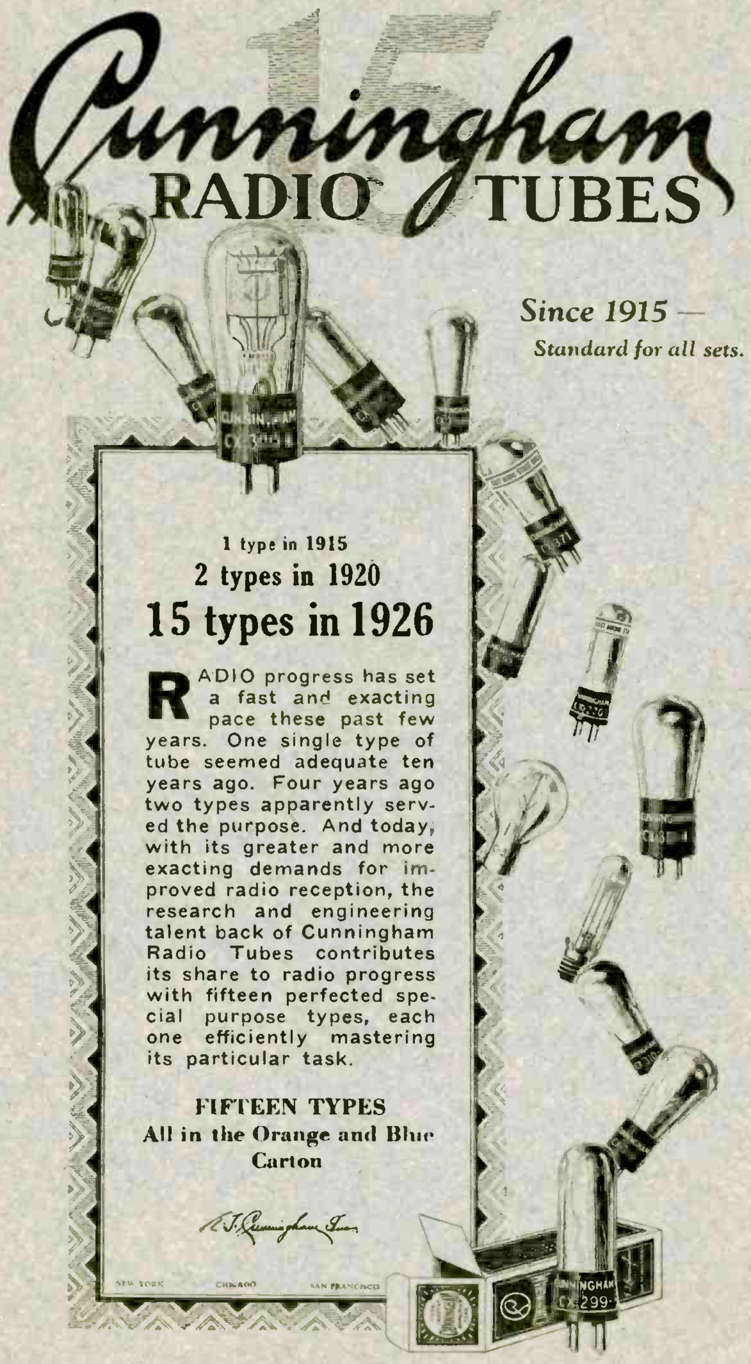

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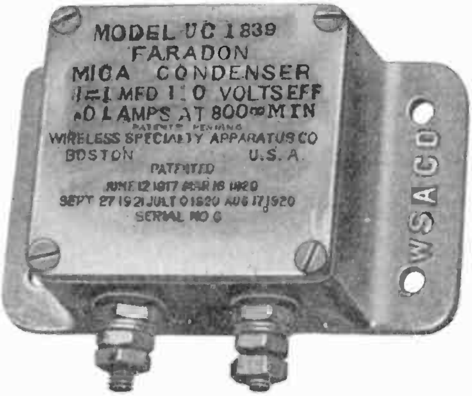
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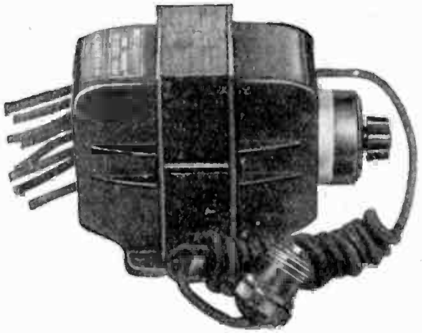

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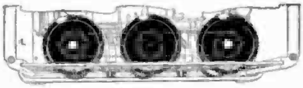

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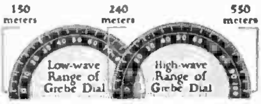

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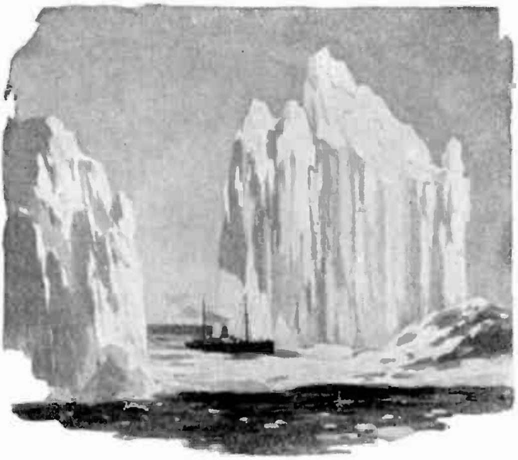

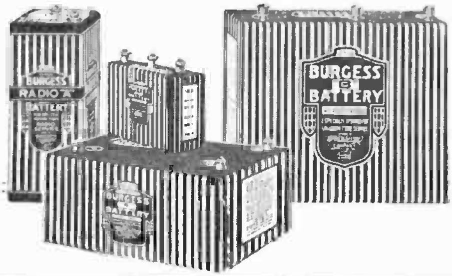
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PROCEEDINGS OF

The Institute of Radio Engineers

Volume 15 JANUARY, 1927 Number 1

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INSTITUTE ACTIVITIES

NEW YORK MEETING, DECEMBER 1.

At the December meeting of the Institute, held in the Engineering Societies Building, two papers were presented: one by Sylvan Harris, entitled "Notes on the Design of Resistance-Capacity Coupled Amplifiers," and one by M. Baumler entitled "Simultaneous Atmospheric Disturbances in Radio Telegraphy." The latter paper was read by Mr. D. K. Martin, and Mr. Harris' paper was read by Mr. D. E. Harnett. There was a very thorough discussion of the papers; participated in by Dr. J. H. Dellinger, C. M. Jansky, Jr., Roy A. Weagant, R. H. Marriott, Arthur Lynch and others. About two hundred members attended the meeting.

DECEMBER MEETING OF BOARD OF DIRECTION

At the meeting of the Board of Direction, held at Institute headquarters on December 1, the following were present: Donald McNicol, president; Dr. J. H. Dellinger, past president; W. F. Hubley, treasurer, and the following Managers: L. A. Hazeltine, Melville Eastham, J. V. L. Hogan, A. H. Grebe, R. H. Marriott and L. E. Whittemore.

The following were transferred to Member grade: Baldwin Guild, A. V. Simpson, L. E. Taufenbach, R. B. Stewart, H. W. Holcombe, D. K. Martin, George Uzmann and K. S. Johnson. Direct elections to Member grade: E. G. Widell and R. W. Seabury.

Fifty-seven associate members and seven junior members were elected.

Report was made of the establishment of a Section of the Institute at Hartford, Conn.

MEMBERSHIP CARDS FOR 1927

The Card of Membership issued to Associates was first distributed to all Associates in the year 1926. The new cards for 1927 are ready and are being sent to all Associate members upon receipt of dues for the coming year. The new cards are of an attractive orange color.

SECTIONS COMMITTEE

The Sections Committee, D. H. Gage Chairman, held a meeting at the chairman's office 253 Broadway, New York on the afternoon of November 23rd. The committee has done good work in connection with Section development and has plans under way looking to the establishment of additional Sections in territories where there is a large enough number of members of the Institute, or where such membership could be built up.

News of the Sections

SEATTLE SECTION

The Seattle Section held a meeting on November 6th in the Club Room, Telephone Building, Seattle, Washington. The meeting was addressed by Mr. Walter A. Kleist on the subject of "Picture Transmission as Employed by The Bell System." The paper was illustrated by lantern slides and was discussed by various members present including Mr. Libby, Roy Batch and C. E. Williams. Twenty-five members attended the meeting.

A meeting of the Section was held on December 4th at which Mr. Albert Kalin gave a talk on the subject of "Transformer Leakage."

ROCHESTER SECTION

The Rochester Section held a meeting on the evening of November 19th. A paper was presented by Mr. H. A. Wheeler, of John Hopkins University on the subject "Applications of Thermionic Amplifiers". Fifty members were in attendance.

The Section held a meeting on the evening of November 30th at which Mr. W. A. McDonald, of the Hazeltine Corporation read a paper on the subject "Importance of Laboratory Measurements in Design of Radio Receivers."

LOS ANGELES SECTION

The Los Angeles Section held a meeting in the auditorium of the Y. M. C. A. of Los Angeles on the evening of September 20th. Mr. H. Pratt gave an interesting talk on the subject "The Problems of The Radio Engineer." Thirty-five members attended the meeting.

A meeting of the Section was held in the Commercial Club Rooms on the evening of November 22nd. A paper was presented by J. J. Jakosky on the subject "Phonographs Adapted to Radio Amplifiers" and a paper by H. M. Tremain on the subject "The New Electric Phonograph."

The meeting was preceded by a dinner. Thirty-five were in attendance.

PHILADELPHIA SECTION

The Philadelphia Section held a meeting on the evening of November 19th at which a paper was presented by Dr. D. Galen McCaa on the subject "Development of an Anti-Static Device". Thirty-five members attended the meeting. The next meeting of the Section will be held in the latter part of January, 1927.

CANADIAN SECTION

The Canadian Section held a meeting on the evening of November 24th in the Electrical Building of the University of Toronto. Professor A. M. Patience presented the paper "Output Characteristics of Amplifier Tubes" by Warner and Loughren. Twenty-one members attended the meeting.

The Section held a meeting on the evening of December 8th, at which Professor E. F. Burton of the University of Toronto presented a paper on the subject of "Physical Characteristics of the Human Voice."

WASHINGTON SECTION

The Washington Section held a meeting on the evening of November 10th in the Conference Room, Department of Commerce. A talk was given by Dr. A. H. Taylor on the subject "Recent High Frequency Progress". There were seventy-five members in attendance.

A meeting was held on the evening of December 8th in the rooms of Harvey's Restaurant of Washington. A paper was prepared by Dr. J. H. Dellinger on the subject "Effect of Fading on Broadcasting" was delivered by Dr. C. B. Jolliffe. There were forty members in attendance. The technical meetings of the Section are preceded by dinner at Harvey's Restaurant.

CONNECTICUT VALLEY SECTION

The Connecticut Valley Section held a meeting on the evening of December 3rd in the auditorium of the Hartford Electric Light Company. A paper was presented by Mr. Allen D. Cardwell on the subject of "The Engineering Design of High Voltage Variable Condensers." In addition there were motion picture exhibitions of interest to communication engineers.

ERRATA

The following corrections should be noted in the paper by Levin and Young in the Proceedings for October, 1926.

Page 681, 10th line from top, i should be I.

Page 683, equation 17, X should be γ: 13th line from top, $a=B_z$ should be $a=B\gamma$: 7th line from bottom, transmission should be transformation; 6th line from bottom $(a-1)$ should be $(Z-1)$.

Page 686 top line i should be I: 2nd line, $\frac{4i}{2i}$ should be $\frac{4I}{2I}$: 3rd line from bottom, $\frac{2}{7}$ should be $\frac{2}{9}$.

Page 688, last term of first equation should read $-j\,\frac{2\pi c}{\lambda}\,CV$

PIEZO-ELECTRIC CRYSTAL-CONTROLLED TRANSMITTERS*

By
A. Crossley

(Naval Research Laboratory)

Introduction

The importance of producing vacuum tube transmitters which generate a constant frequency has never been seriously considered until recently, when the advent of broadcasting stations and the increasing number of ship and shore radio stations has demanded that such transmitters be made available.

The Naval Radio Service has been faced with this problem for a number of years particularly in the operation of the United States Fleet. Such a fleet generally consists of a group of vessels, numbering from 150 to 200 ships, which move as one unit and, for the greater part, their movements are controlled by radio. These vessels have one or more transmitters on board and are required to be in constant touch with each other and also with a group of shore stations. When we consider such a large number of stations, as represented by this Naval force it is very easy to imagine the confusion that will result if no means are employed to maintain a constant frequency for each station's transmitter.

Various means have been employed to hold constant the frequency of transmitters, but no absolutely satisfactory means has been devised which will maintain a constant frequency in vacuum tube transmitters which employ self oscillating circuits. This statement has special reference to transmitters which are required to operate over a band of frequencies and are dependent for plate and supply filament power on the usual ship's dynamo or shore stations power sources.

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*Received by the Editor December 10, 1926.

When we consider that the beat note of a continuous wave transmitter has to remain within a certain tolerance, say 350 cycles, it can be realized that the constant frequency condition becomes harder to meet as the frequency of the transmitter is increased. This can be readily seen when we consider that the frequency of a 4000-kc. transmitter cannot be changed more than 1/100 of one per cent before it has exceeded the specified frequency tolerance.

Realizing, after years of experimentation, that we could not meet the demands made on us by the Fleet with vacuum tube circuits employing the self-oscillating principle it was necessary to turn to some other means for meeting this demand. One means which has proved successful is the piezo-electric crystal-controlled transmitter. Such a transmitter has been found to meet all our requirements if suitable means are provided to keep the temperature of the crystal constant.

In order to cover development work undertaken at the Naval Research Laboratory the following paper is presented together with a resume of the art as observed.

THE PIEZO-ELECTRICAL CRYSTAL

There are a number of crystalline substances such as quartz, tourmaline and Rochelle salts which have excellent piezo-electric and pyro-electric properties. All these are from an optical standpoint doubly refracting and possess asymmetric atomic structure. Bragg and Gibbs[1] show that alpha quartz which is piezo-electrically active has an unsymetrical hexagonal atomic structure, while beta quartz which has no piezo-electric properties is of a regular hexagonal atomic structure.

It is only natural to assume that any crystalline body which has double refracting properties and whose atomic structure is unsymetrical should be piezo-electrically active. F. Pockels[2] states that 20 out of 32 crystalline substances show some piezo-electric properties.

Considering the three commonly known piezo-electric crystals, i. e., quartz, tourmaline and Rochelle salts, we find that quartz is to be preferred. Rochelle salts although it has ten times the piezo-electric properties of quartz is not reliable. It is fragile, extremely hard to manufacture and

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[1] Bragg & Gibbs—Proc. Royal Society, Vol. 109—1926.

[2] Winkelmanns Handbuch der Physik No. 2.

its physical dimensions can be easily changed by handling, especially when subjected to contact with water. It also will not stand any electrical load; for instance, if used as a resonator in connection with the output of an oscillator of a few watts capacity it will break down. This breakdown will either be in the form of a series of mosaic cracks throughout the crystal or it will consist of a melting process wherein the crystal suddenly flattens out and assumes an isotropic state. If the power is increased the salts will return to a liquid state.

Repeated attempts have been made to make Rochelle salt crystals function as well as quartz, for controlling the frequency of a vacuum tube transmitter, but no success has been obtained in this endeavor. The Rochelle salt crystal is not mechanically strong enough to withstand the vigorous vibration which is met with in the quartz crystal when controlling the frequency of a vacuum tube transmitter. It is also possible that the hysteresis losses in the Rochelle salt crystal are such that they tend to damp out any properties of the crystal for generating a return piezo-electric voltage required for maintaining a vacuum tube circuit in an oscillating condition.

There is no literature available which shows the application of Rochelle salt crystals as a means for controlling the frequency of a vacuum tube circuit.

Tourmaline is too expensive to be considered as a commercial product and therefore resort has to be made to the use of quartz.

Quartz can be obtained in reasonable quantities in Brazil, Madagascar, Japan and the United States. Any quartz which has no flaws, intergrowths or optical twinning can be so manufactured that it has excellent piezo-electrical oscillating properties. By this we mean that such a crystal can be used to control the output of a vacuum tube oscillating circuit at one definite frequency and with maximum output.

Quartz will retain its physical dimensions if kept at a definite temperature. It will also stand considerable abuse, which accompanies its use in oscillation test circuits, where the crystal is heated momentarily to temperatures in excess of 45 deg. cent. and is subjected to frequent washing. Experience has demonstrated that crystals will hold the original oscillation frequency for periods in excess of ten months, when operated continuously in a high-frequency transmitter system. Other exacting tests have proved that quartz is the only material known which is satisfactory for use in crystal-controlled vacuum tube circuits.

The quartz crystal is hexagonal in shape and when in its true form has an apex at each end. The methods of mining and also the process of growing are such that the two apexes are rarely found on crystals which are purchased from the importers. In the majority of cases it is rare to obtain crystals having sides and one apex which are not chipped or cracked due to rough handling or poor mining methods.

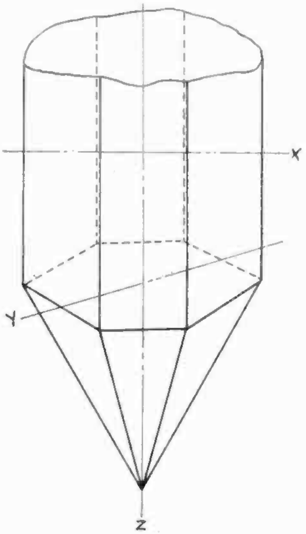

Figure 1

The usual crystal when received is similar in shape to that shown in Fig. 1. In this crystal the optical axis is parallel to an imaginary line *Z* which is drawn between two apexes. The electrical axes are of two types, one which is parallel to a line *X* drawn between the corners of the hexagonal sides and the other which is parallel to the line *Y* which is drawn between the opposite flat faces of the hexagonal sides. From this we note that there are three *X* electrical axes and three *Y* electrical axes and one optical axis. The optical axis is always at right angles or perpendicular to any of the electrical axes.

Now cut a slab of quartz from the crystal as shown in Fig. 2 making this cut at right angles to the optical axis *Z*. Then in order to obtain a workable crystal we cut a slice from this slab as shown in Fig. 3. This slice is so cut from the slab that the slicing produces a crystal which sides are parallel to one of the *Y* electrical axes and at right angles to one of the *X* electrical axes. We now have a crystal whose thickness represents an *X* axis, whose length a *Y* axis and the depth a U or optical axis.

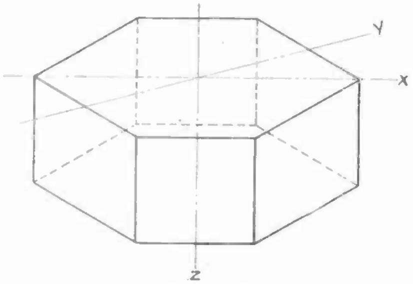

Figure 2

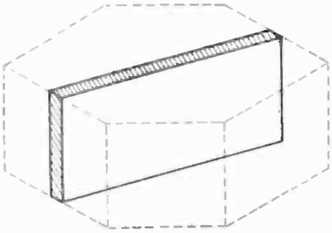

Figure 3

Methods of manufacturing the crystal from this point on to the perfect oscillating condition is being made the subject of another paper.

Having completed the cutting of the crystal which we will term the "Currie 3" or "zero angle cut" we find that there are three frequencies to which the crystal will resonate. One frequency corresponds to the *X* dimension, one to the *Y* dimension and the other to a frequency which is between *X* and *Y* axis frequency and is termed the coupling frequency. This coupling frequency depends on the dimensions of the *X* and *Y* axes. In round crystals as shown by Hund [4] the *X* dimension will produce 104.6 meters per mm.,

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[4] A. Hund. Proc. I. R. E. August 1926.

the *Y* dimension 110.5 meters per mm. and the coupling frequency is equal to 0.71 of the *Y* dimension wave length. In rectangular crystals the meters per mm. for the *X* dimension varies from 103.5 to 105.0 while for the *Y* dimension it varies from 110 to 117 meters per mm. The meters per mm. obtained for the coupling frequency cannot be stated because it depends on the dimensions of the rectangular form which may be square or any shape which the requirements demand. These figures are based on the true Curie cut and on crystals whose *Y* dimension is between 20 and 28 mm. If any cut is made which is at an angle from the Curie cut the meters per mm. will be greater, especially for the *X* dimension oscillation.

Rectangular crystals are to be preferred to round crystals, first because they are cheaper to make and second because they will control a greater radio frequency output without cracking or chipping. The latter condition is probably explained by the uneven stress conditions present in round crystals when they are oscillating under influence of radio frequency currents.

HISTORY

P. and J. Curie[3] first investigated quantitatively the piezo-electric properties of quartz and derived equations showing the relation between the applied pressure and the piezo-electric charge on the faces of the crystal. They also showed the converse effect where an electric charge on the crystal would produce a change in crystal dimensions.

Since this disclosure, various uses have been made of piezo-electric crystals, namely, as pressure gauges, loud speakers[5] and sound transmitters for underwater signalling[6].

Cady[7] first discovered that quartz could be employed as resonators and as such to be used as standards for precision frequency determinations. Cady later discovered that crystals could be used to hold the frequency of self-oscillating circuits constant and also that crystals could be made to control the frequency of a vacuum tube circuit. It is this feature of crystal control that we are most interested in and in order to present this subject we will consider each step made by various investigators in producing vacuum

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[3] P. & J. Curie, Journal Physique, 2 series, Vol. 8. 1889—p. 149.
[5] A. Mc.L. Nicholson patent U. S. 1,495,429—May 1924.
[6] Paul Langevin British patent 145,691—July, 1921.
[7] Cady patent U. S. 1,450,246 Apr. 1923.

tube circuits which would be capable of obtaining maximum radio frequency output from a quartz crystal.

Cady's work may be summarized by reference to Figs. 4, 5, and 6. The circuit shown in Fig. 4 is essentially a self oscillating vacuum tube circuit with a crystal placed across the grid tuning condenser. When the circuit is adjusted to the resonant frequency of the crystal there is a tendency in the crystal to keep the frequency of the circuit equal to that of the crystal. If the plate voltage, filament voltage and load remain the same, the crystal will hold constant the frequency of the circuit, but if one or more of the above conditions are changed the circuit will oscillate at any frequency which the circuit conditions permit.

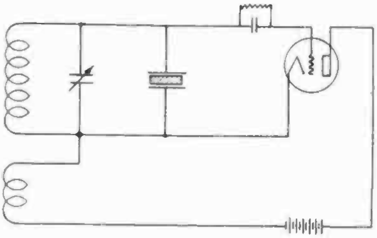

Figure 4

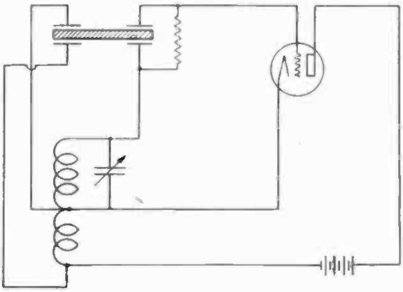

Figure 5

Fig. 5 is an elaboration of Fig. 4 and is employed to obtain a greater piezo-electric voltage for controlling the frequency of the circuit. The greater piezo-electric voltage is obtained by the use of the plate feed back principle represented by the extra set of plates on the crystal. The operation of this circuit is limited by the same conditions which are cited for the circuit shown in Fig. 4.

It has been our experience that any method which depends on any self-oscillating conditions in a vacuum tube circuit in addition to piezo-electric control is dangerous for two reasons: i. e., first, because of the danger of frequency shifting and second it is very easy to crack or chip crystals in such circuits. This latter case is exaggerated when we tie in the crystal oscillating circuit with an unbalanced amplifying system where the radio frequency current feedback from the amplifying circuit is sufficient to supply enough additional current through the crystal to cause it to heat up and crack.

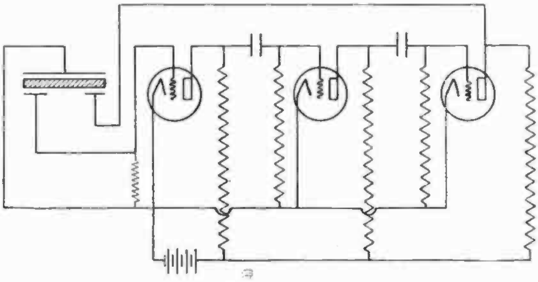

Figure 6

Fig. 6 is the first circuit known to the art wherein the crystal with the associated amplifying circuits comprise a system in which the crystal is the only control for the generator frequency. In this circuit the initial piezo-electric charge on the grid is amplified through three stages of resistance-coupled amplification, and by the means of a third contact plate on the crystal this amplified charge is applied to the crystal in the right phase relationship to reinforce the initial charge and by this process assist the circuit in generating radio frequency currents.

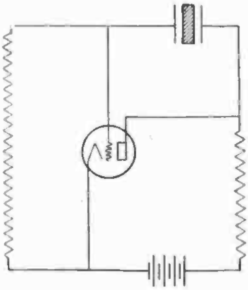

Figure 7

Pierce[8] later developed a circuit shown in Fig. 7 which is capable of generating by the use of crystal control a

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[8] Pierce Journ. AMN. Academy of Arts and Sciences, Oct. 1923.

source of constant frequency. In this figure the crystal is placed between grid and plate of a vacuum tube and a resistance load is inserted in the plate circuit. A grid leak is employed to hold the grid at a certain voltage with respect to the filament.

Fig. 8 is a modification of Fig. 7, wherein an inductance is substituted for the plate resistance. Both of the Pierce circuits function in the same manner as the old De Forest Ultraudion circuit. In the Ultraudion circuit, a tuned circuit is interposed between grid and plate as shown in Fig. 9 and a choke coil was employed as a load in the plate circuit. This choke coil was so constructed that it acted as a capacitive load for all frequencies to which the tuned circuit was resonant.

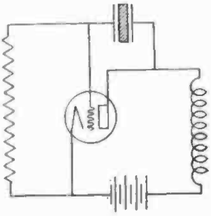

Figure 8

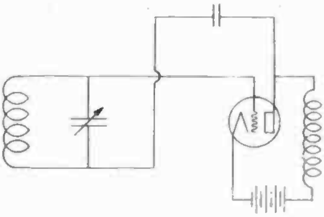

Figure 9

In the Pierce circuits the crystal functions as a tuned circuit having a preponderance of inductance while the plate load for the condition of oscillation has to be capacitive. To accomplish this end, Pierce uses a very large inductance coil in the plate circuit. The true inductance and the distributed capacity of the coil system used in this circuit has to be such that it will resonate to a lower frequency than that of the crystal before the circuit will oscillate. In the case where resistance is used, as in the plate circuit of

Fig. 7, it is the distributed capacity of the resistance together with plate-filament capacity that affords the capacitive reactance required for the oscillation condition.

If the proper precautions are observed with the Pierce circuit with respect to the capacitive plate load condition, any crystal can be made to trigger off this circuit into the oscillating condition. In view of the fact that a grid leak is employed and the plate load is a resistance or a large inductance it is not possible to obtain the rated power output from a given tube with this circuit. This statement is based on the fact that the I^2R losses in the resistance and inductance are considerable and the grid leak method of biasing is inefficient for reasons which will be explained later in this paper. There is another objection to the Pierce circuit and that is the broad impedance curve of the plate circuit, which permits the generation of a number of oscillations at one time should the crystal be so constructed that there are two possible oscillations, for the *X* dimension or the *Y* dimension frequency may be very close to the coupling frequency with the result that both frequencies will be heard.

PIEZO-ELECTRIC CRYSTAL RESEARCH WORK AT THE NAVAL RESEARCH LABORATORY

Realizing the limitations of piezo-electric crystal circuits then known to the art, further development work was carried on at the Naval Research Laboratory to determine whether piezo-electric crystals could be employed to control any system which could permit a reasonable radio frequency output.

J. M. Miller formerly of this Laboratory developed the circuit shown in Fig. 10. This circuit is similar to Pierce's circuit with the exception that Miller employed a tuned plate circuit and a variable tap on the inductance. The tuned circuit permitted tuning to any desired frequency, thus ex-

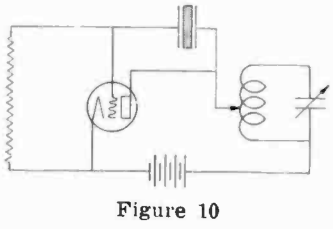

Figure 10

cluding undesired frequency oscillations. The variable plate tap permitted matching of tube impedance to circuit impedance whereby maximum power transfer was possible. Low loss inductance and condensers were employed thus reducing I^2R losses in the tuned circuit to a minimum

Miller also developed the circuit shown in Fig. 11, which circuit is the fundamental Navy circuit. In this circuit the crystal is placed between grid and filament instead of between grid and plate as in Fig. 10. With this circuit the load for the plate circuit should be inductive in order that a condition for oscillation be obtained. The action of this circuit with reference to the oscillating condition is similar to the well known Hartley self-oscillating circuit. This may be better understood by stating that the crystal, being equivalent to an inductance, is similar to the grid coil of the Hartley circuit, while the inductive load in the plate circuit of the crystal oscillator is identical to the plate coil of the Hartley system.

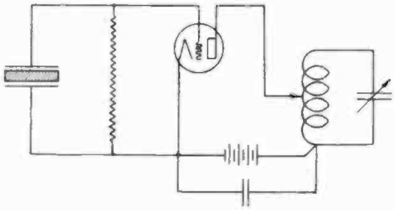

Figure 11

Miller demonstrated that he could make both circuits oscillate with crystals of different frequency ratings. Preference was given to the use of the circuit shown in Fig. 11 because in such a circuit there is no tendency for short-circuiting the high-voltage plate circuit should the crystal crack or slide out from between the contact plates thus causing the plates to come in contact with each other. Experiments with high-frequency crystals show that good output is obtained with high as well as low-frequency crystals when employed in the circuit shown in Fig. 11.

The problem of obtaining greater output from the crystal oscillating circuit and the amplification of this output on low frequencies was assigned to A. Crossley. The Miller circuit Fig. 11 was used as a foundation and efforts were made to increase its radio frequency output.

A study of this circuit showed that the crystal-controlling voltage was reduced materially by the fact that a grid leak was shunted across it. This grid leak provided a shunt path for the radio frequency piezo-electric control voltage and at the same time carried the rectified grid current required for obtaining the negative voltage for biasing the grid. Miller suggested the use of a choke coil in series with the grid leak to eliminate that part of the radio frequency voltage loss that is due to the direct flow of current through the grid leak resistance. This materially increased the output of the crystal oscillating system.

Crossley eliminated the second load on the crystal by substituting a battery for the grid leak, connecting the negative terminal of the battery to the low radio frequency potential side of the choke coil shown in Fig. 12.

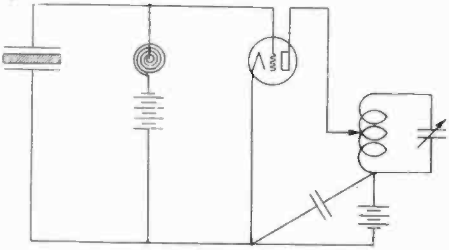

Figure 12

The object of the use of the battery was to keep the swing of the crystal-controlling voltage over on the negative side of the grid voltage-plate current characteristic curve, thus eliminating the load in the grid-filament path which is obtained when the grid swings positive past the zero grid voltage point on this curve. The act of swinging over the positive side of grid voltage-plate current characteristic curve causes a current flow between grid and filament which represents an I^2R loss. Any method for eliminating this grid current flow or rendering it of negligible value will also permit the crystal controlling voltage to be kept at a maximum and therefore permit a maximum output to be obtained from the circuit.

In actual practice, there is a small amount of grid current flowing, but the grid voltage swing is for the greater part over on the negative side of the grid voltage plate-current characteristic curve. This grid current flow is due principally to the fact that the grid battery employed does not block the plate current to zero, because a small amount of plate current is necessary before the crystal circuit will start oscillating.

The use of the battery increased the output of the circuit tremendously. Using a 600-kc. crystal it was possible to obtain one watt output with the original circuit employing the grid leak while with the choke and battery an output of 21 watts was obtained. The tube used in this experiment was the U V 210 type rated at 7½ watt allowable plate dissipation. The efficiency of this circuit was 65 per cent figuring plate input watts against radio frequency output. The plate voltage for this test was 650 volts, while the grid battery was 80 volts.

Further experiments with 50-watt tubes and also special tubes, have shown that as high as 100 watts output can be obtained when employing high-frequency crystals in the 3000 to 4000-kc. band. It is not possible to obtain such outputs when employing higher or lower frequency crystals. With the lower frequency crystals the feed-back afforded by the grid-plate capacity is proportional to the frequency, while the capacity between crystal plates is reduced as the frequency of the crystal is decreased. In other words the charge on the crystal is reduced as the frequency of the crystal is decreased and correspondingly the piezo-electric controlling voltage from the crystal is likewise reduced. To make up for the reduced charge on the crystal it is customary when using lower frequency crystals to increase the plate and grid battery voltage.

There is, however, as stated before, a certain high frequency where maximum output is obtainable and on either side of this frequency there is slow decrease in output. Around 3500 kc. is approximately the peak output frequency point, while at 12,000 and at 100 kc. are the frequencies where minimum output is obtained. These output ratings, are based on safe crystal current-carrying ratings, which was first shown by A. Hoyt Taylor. Taylor shows that for the different frequency crystals there is a safe working current at which the crystal can be operated and if this point is exceeded the crystal will heat up and crack.

This condition can also be tied down to a safe wattage dissipation in the crystal, but not knowing the resistance of the crystal we can only consider it from a current standpoint. In the 3000 to 4000 kc. band, electrostatic voltmeter and thermal ammeter readings in the crystal circuit show approximately five watts loss in the crystal. It is only at this and higher frequencies that an electrostatic voltmeter can be used to measure the voltage across the crystal, because the shunting effect of the capacity of the meter at the lower frequencies is such that it seriously reduces the output. When measurements were made with a 500-kc. crystal, the placing of an electrostatic voltmeter across the terminals of crystal holder was such as to reduce the output to less than one-half of the original output. This reduction in crystal piezo-electric controlling voltage is due to the fact that the plate-grid feed-back voltage is divided between the two capacities, i. e., the voltmeter capacity and the crystal capacity, while at the lower frequencies the crystal capacity is nearly equal to the voltmeter capacity.

This can be shown further by reference to Fig. 13 where *Cr* is the capacity equivalent to the crystal, capacity *Cv* represents the voltmeter capacity of *Cf* the grid-plate feed-back capacity.

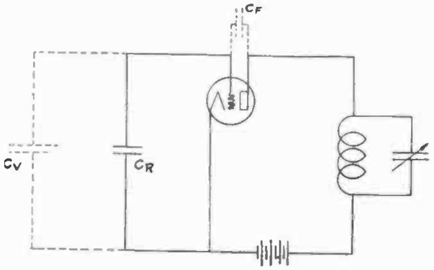

Figure 13

From the above figure we can note that it is not possible to obtain true voltmeter readings due to the presence of the shunt capacity *Cv* which divides the feed-back charging voltage into two paths, thus robbing the crystal of the maximum charging voltage from the plate circuit. Although we have cited the case of the shunt capacity afforded by the voltmeter, it is also true than any extraneous capacities, such as long leads from crystal to grid, poor design of crystal holder which permits additional capacity other than that of the crystal contact plates, and choke coils which have high distributed capacities, will also produce the same effect.

The capacity between contact plates of crystals in the range between 100 and 12,000 kc. respectively, varies from 12 to 125 micromicrofarads. When we consider the capacity of the crystal and the fact that the grid-plate feed-back capacity is constant, it can be readily seen when using the same plate voltage, that the charge delivered to the crystal is reduced with the decrease of frequency. An example of this case is cited by comparing charges delivered to two crystals, i. e., a 500 and a 4000-kc. crystal when employed in a 7½ watt U V 210 tube circuit. With the 4000-kc. crystal the charge is 64 times as great as that delivered to the 500-kc. crystal. This increased charge on the crystal with the increase of frequency explains why it is possible to obtain greater radio frequency output at high frequencies and why we have to be so particular about low-frequency crystals and their associated circuits. With the low-frequency crystals it is imperative that we employ the right amount of grid biasing voltage for the condition of maximum output, while with the high-frequency crystals it is possible to eliminate the biasing voltage and still obtain good output. It is, of course, understood that the elimination of the biasing battery means a reduction in the efficiency of the circuit and sluggish oscillating action of the crystal, especially when we use the crystal as a master oscillator.

An improvement on the Miller circuit was made by Crossley and is shown in Fig. 14. This improvement provides for the isolation of the radio frequency output circuit from the high-voltage direct-current circuit thus preventing the operator from accidentally coming in contact with the high-voltage direct-current supply. The insertion of the choke coil *L* and the condenser *C* in the circuit permits the segregation of the radio frequency and direct-current cir-

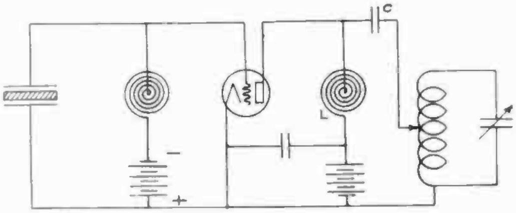

Figure 14

cuits. It is good practice to make the resonant period of the plate choke coil *L* equal to a frequency which is lower than that of the crystal, thus making the choke coil a capacitive reactance at the crystal frequency.

CRYSTAL HOLDERS

The subject of crystal holders is very important. Experiments conducted by Crossley, particularly in the low-frequency range, show that the crystal will become inoperative if any dirt or moisture comes in contact with the crystal. If a crystal is placed in a circuit and started oscillating and a minute drop of water or oil is placed on the crystal, it will immediately stop oscillating. The stopping of oscillations may be explained when we consider that for best operation the top crystal contact plate is separated by a minute air cushion from the surface of the crystal when the crystal is oscillating and the introduction of moisture in place of the air causes a load to be placed on the crystal. This latter condition is similar to the use of mercury as a contact surface for the crystal, which type of contact adheres so closely to the crystal that it damps out any oscillation that tries to start up.

From the above facts it is imperative that the crystal be placed in a hermetically sealed container where no moisture or dirt can come into contact with it.

It is necessary that capacities other than that between the crystal contact plates be kept as small as possible, thus eliminating the charging losses occasioned by extraneous shunt capacities. For reliable operation and maximum output the crystal contact plates should be intimately touching the surface of the crystal. Lapped surfaces on these plates are to be preferred, while the weight of the upper plate should be kept to a minimum. No restriction of up and down movement of the upper plate should be tolerated. Light spring pressure can be applied to this plate but for best results no pressure other than the weight of the plate is necessary.

Retaining rings of bakelite or other insulating material or brass retaining pegs can be employed to hold the crystal in one fixed position with respect to the sides of the container. A holder[9] having all these features together

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[9] Crossley patent U. S. No. 1,572,773—Feb. 1926.

with means for restricting the tendency for the crystal to jump clear of the retaining pegs when being transported is shown in Fig. 15.

Experience has shown that any air-gap between upper surface of crystal and the contact plate means a great reduction in output and when used in regular power circuit the air-gap causes brushing between the surface of the crystal and the plate, which in turn causes the crystal to heat and crack. Crystals which have been subjected to the brushing effect show a discoloration on the surface of the crystal at the place where the brushing occurred.

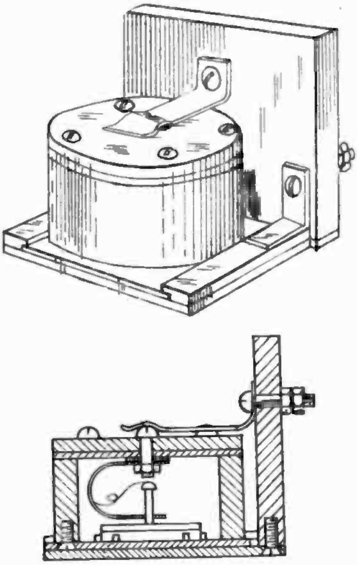

Figure 15

The frequency of any crystal changes with temperature and for absolute constancy of frequency it is necessary that some type of temperature control be applied either directly or indirectly to the crystal. One method is to place the crystal in a hermetically sealed container and by use of a thermostat and heating unit in this container maintain the crystal at a predetermined temperature. The second method is to place the crystal in a crystal holder of similar type to that shown in Fig. 15 and to secure this holder on a metal plate which can be maintained at a constant temperature.

The heat from the plate will be conducted through the lower crystal contact plate direct to the crystal.

The metal heating plate can be kept at a constant temperature by circulating water through it, or a sub-compartment with suitable heating unit and thermostat can be attached to this plate. A thermostat can be employed with the water circulating system to turn on or off the current in a heating coil which is placed in the water intake line to the plate. This latter water-cooling method was developed by Taylor and applied by E. L. White to the high-power high-frequency transmitters at this Laboratory.

The importance of constant temperature control is appreciated when operating high-frequency crystals, as a change of 10 deg. cent. will change the frequency as much as one kilocycle in the 4000-kc. range. Extreme changes in temperature met with on board Naval vessels when cruising can change the crystal frequency as much as three kilocycles, which charge is very detrimental to perfect communication conditions. A remedy for this is to provide a thermostatic control which will maintain the crystal temperature above that which is ever encountered, throughout the year. This is identical with the practice now in force with reference to our Navy Standard 25-kc. crystal calibrator, which is used as a standard of frequency for the Navy.

Recent data on temperature coefficient in quartz crystals obtained by the Naval Research Laboratory show for the *X* axis there is a frequency change of 25 parts in a million per degree centigrade while with the *Y* axis a change of 50 parts in a million is noted. These data on electrical characteristics appear to show that the temperature coefficient of the elastic constant along the *Y* axis is approximately double that of the *X* axis, as we can assume that the frequency change must tie in with the mechanical change. This statement is based on our previous experiments on the resonant condition, in crystals, namely, the relation of meters per millimeter for respective electrical axes.

Several types of multiple crystal holders have been developed. One type employs the holder shown in Fig. 15 which was placed on a circular disk with a knob and pointer on the front of a panel for rotating the disk. Two contactors are placed behind the panel for making contact with each crystal holder as it was rotated past the indicated point.

CRYSTAL CONTROLLED POWER AMPLIFIERS

Having obtained reliable operating conditions with the crystal controlled oscillator our next and most important problem was to amplify this output.

The first attempt to amplify the crystal oscillator output was made by resort to two stages of amplification. The first stage consisted of a 7½-watt tube while in the second stage two 50-watt tubes were employed. Grid leaks were used to bias the grids of the amplifier tubes. An output of 96 watts was obtained with this power amplifier at a frequency of 600 kc. Another stage of amplification consisting of three 250-watt tubes was added to this amplifier and the maximum output obtained was approximately 700 watts.

About this time Dr. Taylor and L. C. Young demonstrated that amplification of power from a 3000-kc. crystal oscillator was possible.

Considerable trouble was experienced from self-oscillations in the amplifier system. Various methods were employed to eliminate these undesired frequencies with no satisfactory result. Crossley discovered that these oscillations were in general of a high-frequency nature and that the only method of eliminating them was to place a resistance of a certain value in the plate lead, preferably as close to the plate as possible. The location of this resistance in the plate lead placed a load on the high-frequency circuit and if sufficient resistance was inserted the load would be too great to permit the grid-plate feed-back to cause a condition of self oscillation. The maximum value of the resistance did not exceed 300 ohms at 300 kc. and can be very low on sets of very high frequency; that is, small enough to have a negligible effect on the output of the amplifier circuit at the amplified frequency. This can be better understood when we consider that the plate circuit impedance at the desired frequency is at least 5000 ohms at medium frequencies for all types of tubes other than the one-kw. type, and the additional resistance placed in this circuit for purpose of stopping self oscillations never is greater than 6 per cent of the total circuit impedance. The impedance of the plate circuit which it is resonant to the self oscillation frequency is low, and the resistance referred to above is so located that it is in series with this resonant circuit.

The importance of shielding each stage of amplification was soon apparent and this was accomplished by providing metal containers for each stage. It was noted that there was sufficient feed-back through the grid plate capacity of the amplifier tubes to prevent maximum power amplification per stage. L. A. Gebhard and Miller suggested and demonstrated the power amplification gain which is possible when neutralizing the feedback and also applying a high value of biasing voltage to the grid of the amplifying tubes.

The neutralizing of the feed-back in the amplifier tubes permitted maximum grid excitation while the use of the high value of grid biasing voltage reduced grid-filament circuit losses to a minimum. A power amplification of 80 is obtainable by the method proposed above. A concrete case of this condition is cited when we amplified the output of a 7½-watt tube circuit by use of a UV 851 one-kw. tube and obtained 600 watts. From the above it can be noted that it is possible to reduce the number of stages of amplification very materially, thus eliminating troubles experienced with the excessive number of stages which are required when employing the old method of cascade amplification.

One more source of trouble was experienced in the development of the amplification system, and that was in the choke coils. It was found during numerous incidences that the choke coils would burn up, particularly the plate choke coils. These choke coils were of the single-layer and the pancake universal-wound type. An investigation of the reason for this burning effect showed that the burning occurred at frequencies which were close to the second, fourth, sixth, and other even harmonic frequencies of the fundamental of the choke coil. It then became necessary to make our choke coils such that the danger or burning frequencies would be other than that of the operating frequency of the transmitter.

If the transmitter is required to cover a broad band of frequencies a radical change has to be made in the choke coils. This change consists of using at least three choke coils, preferably of the universal-wound type, in a series connection. Each coil should have the same number of turns and the same shape and arranged on a bakelite or pyrex rod or form in such a way that the magnetic fields add. This multiple choke arrangement provides a method of obtaining in a concentrated form a choke coil which has nearly twice the inductance and two thirds the distributed capacity of the best type single-layer choke coil. It also has, by virtue of the addition of impedance of the respective coils, a high value of impedance at the dangerous harmonic frequencies. This latter characteristic makes this type of choke well suited for use in transmitters which employ the principle of frequency doubling or tripling to obtain super high-frequency oscillations. A choke coil similar to the type referred to above is shown in Fig. 16.

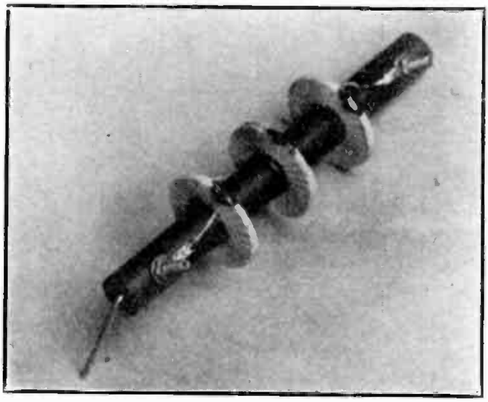

Figure 16

Having solved the major problems involved in the crystal controlled transmitter with reference to output the next problem was that of keying the system. Various methods were tried and abandoned due partly to sluggishness of action or the fact that too large a load was taken from supply source which furnishes the necessary negative voltage for blocking the grid of the control tube. A satisfactory system was finally obtained and may be explained by reference to Fig. 17.

In this figure there is shown one of the stages of amplification which it is intended to key. The grid circuit consists of the blocking condenser 1, choke coil 2, relay 4, high resistance 3 and the battery 5. Associated with the relay 4 is the key 7 and relay battery 8. The plate circuit is of the conventional type and consists of blocking condenser 9, antenna or dummy circuit 10 with the usual plate choke 11 and plate potential source 12.

The keying is accomplished by changing the grid biasing voltage from an operating voltage to a high blocking voltage through the agency of the relay 4 and the associated circuits. With the key 7 closed, current flows through the relay 4 and closes the contacts, thus permitting the grid lead to be connected to the low-voltage tap on the battery 5. The high resistance 3 is then placed across the remainder of the battery and, due to its high value, it takes no appreciable load from the battery 5. When the key is up or in the open position the contacts on relay 4 spring back and disconnect the low voltage tap on the battery 5, thus through the resistance 3 making a path for the high blocking voltage to be impressed on the grid. The fact that there is no current flow through the grid circuit also indicates that there is no *I R* drop over the resistance 3, thus we can, by means of the relay, change the grid voltage from an optimum operating value to an absolute blocking value. The use of the high-resistance also cuts down to a minimum the sparking and sticking of the contacts on the relay. With this method of keying it is possible to key at speeds in excess of 100 words per minute.

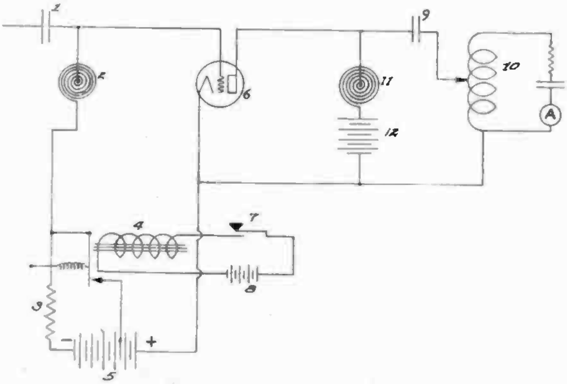

Figure 17

COMPLETE TRANSMITTER

Further work on this problem of amplification at frequencies from 150 to 600 kc. proved that it was possible to obtain an output of 13 kw. into a dummy antenna system. The complete details of the system which is capable of delivering this radio frequency power output may be explained by reference to Fig. 18.

In this figure three stages of amplification are shown. The first stage consists of a 50-watt impedance coupled amplifier which feeds into a 1-kw. tuned amplifier stage and from this stage to a 20-kw. amplifier circuit.

The crystal controlled oscillator consists of a multiple crystal holder with the associated grid circuit which comprises the grid radio frequency choke and the source of biasing voltage. The plate circuit of this oscillator employs the parallel feeds through agency of the multiple choke coil, a source of high direct voltage, a 0.004 radio frequency bypass condenser and a resonant circuit consisting of an inductance and two condensers with suitable radio frequency ammeter. Two condensers, one of which is variable are employed to permit tuning to resonance with the inductance over a given range of frequencies.

Voltage required for exciting the grid of the first amplifier tube is obtained from a tap on the inductance of the resonant circuit. Proper biasing voltage for the grid of the amplifier tube is obtained from a potentiometer and flows through the inductance of the resonant circuit direct to the grid. This method of biasing the grid of the amplifier tube eliminates the usual grid condenser and choke coil system.

The plate circuit of the first amplifier tube comprises a multiple radio frequency choke coil with the usual high voltage direct-current source and a resistance load circuit. The radio frequency output of the choke coil is delivered to the resistance load through the two by-pass condensers shown in the diagram.

The choke coil system is so constructed that it is resonant to a lower frequency than that of the range of the transmitter and therefore provides a capacitive load. This capacitive load prevents any tendency for feedback in the amplifier, thus saving the crystal circuit from any surge effects which tend to overload and break the crystal.

A variable contactor is used on the load resistance for obtaining optimum controlling voltage for the grid of the second amplifier tube. A 0.004-μf. by-pass condenser segregated the radio frequency resistance bad circuit from the grid biasing system. It will be noted that the grid biasing system of this tube includes the keying system referred to previously in this paper.

The plate circuit of the second amplifier has the usual parallel radio frequency feed circuit and in addition there is the balance or neutralizing circuit which comprises the counter-inductance and a 0.0002-μf. variable air condenser. This balance or neutralizing system is found to be very reliable and easy to adjust.

The third amplifier stage is identical to the second stage with the exception of the addition of the antenna load system. As will be noticed, the voltage for feeding the antenna is obtained from the drop across a condenser which is placed in series with the plate resonant circuit. This condenser was a 0.25-μf mica condenser with five taps of 0.05μf each. This condenser in addition to supplying required voltage for the antenna system also functions by virtue of its low impedance in reducing harmonic frequencies to a low value.

PROTECTIVE DEVICES

Various kinds of protective devices were employed in this transmitter. The first and most important protective device was tied in with the biasing battery circuit and functioned in opening the filament and 2500-volt supply when no current was being supplied from the biasing battery.

The second device consisted of a water-flow protective relay circuit. When there was no flow of water through the water-cooled tubes the device opened the filament supply circuit and also the field of the high-voltage generator.

A circuit breaker was placed in series with the negative terminal of the high-voltage generator and when an overload was placed on the generator it opened the generator field circuit.

As a safety-first precaution, a condenser and a resistance was placed across the coil of the circuit breaker. These units maintained the negative side of the generator at ground potential should the breaker coil accidentally open. They also had a tendency to reduce line surges to a great extent by acting as a damping means.

MISCELLANEOUS

Very small output is obtainable from a crystal on the lower frequencies required of the transmitter and for this reason a small amount of regeneration was employed in the crystal circuit. The regenerative feature is shown in Fig. 18, by the grid feed-back coil in the crystal oscillator circuit. On the higher frequencies this coil was short-circuited, for as previously stated in the paper, regeneration, especially at higher frequencies than 400 kc. is liable to crack the crystal.

The 50-watt stage of amplification was required for the low-frequency amplification, but can be dispensed with at the high frequencies. With well made crystals and proper circuits it is possible to use only two stages of amplification and obtain outputs in excess of 10 kw. when operating the transmitter over the range from 400 to 600 kc.

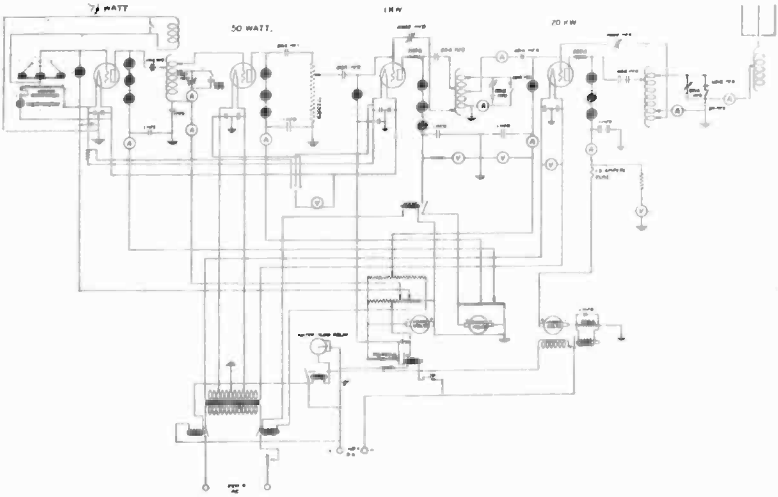

Figure 18

There was no need for frequency doubling in this transmitter and consequently no mention was made of it. Frequency doubling and tripling circuits were developed by Taylor and have been used very extensively in our numerous high-frequency transmitters which are in operation at N. K. F. This principle is also used in transmitters furnished by the Naval Research Laboratory to the Coast Guard, Army, Naval ships and stations.

The work covered in the construction of the low-frequency transmitter was undertaken by A. Crossley with the assistance of W. F. McBride. Messrs. Gebhard, Young, White and Taylor were responsible for the development of the high-power high frequency transmitters.

The development of the low power high frequency transmitter which derives its source of plate potential from alternating-current circuits was undertaken by R. B. Meyer.

Meyer developed the crystal oscillator circuit which employs one crystal and two tubes with the split transformer plate supply circuit. Best results are obtained with such a circuit when the frequency of the supply source is 500 or more cycles. The Meyer circuit is shown in Fig. 19. This circuit is used in transmitters designed and built for the Army and the Marine Corps. A schematic wiring diagram of this transmitter is shown in Fig. 20. An inspection of this

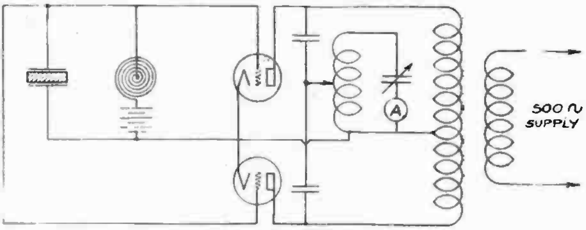

Figure 19

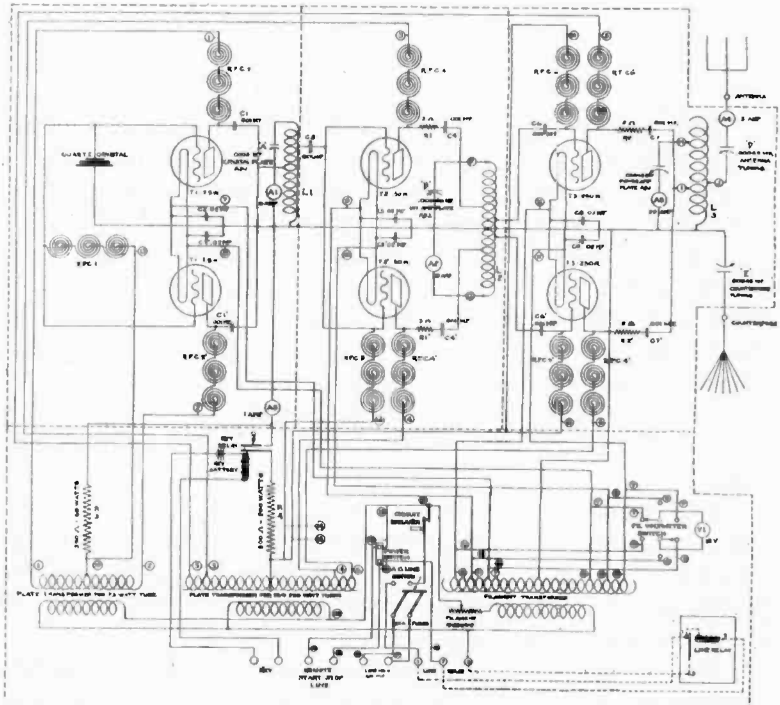

Figure 20

diagram will show the automatic balance which is obtainable in the amplifier circuits when resort is made to the use of an alternating plate current supply. This balance is obtained by using approximately the same number of plate turns in each amplifier tube curcuit.

This transmitter is designed for frequency doubling and is capable of covering a frequency range from 3500 to 9000 kc. The rated output of the transmitter is 500 watts.

Figs. 21 and 22 are photographs of this transmitter showing front and side views.

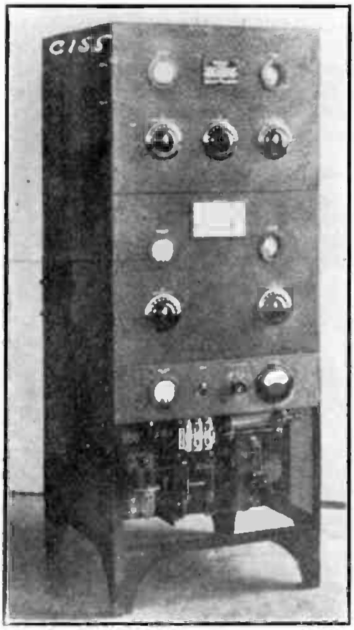

Figure 21

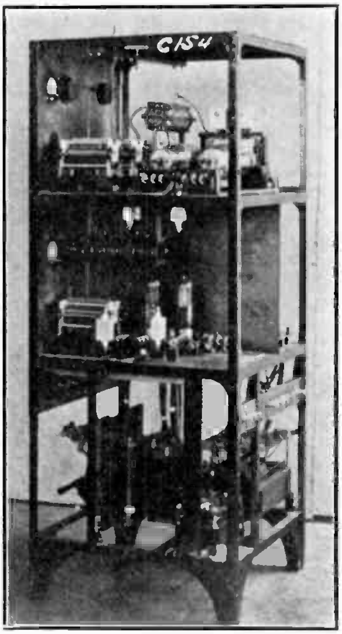

Figure 22

A method for obtaining more piezo electric controlling voltage was developed by Taylor[10]. This is accomplished by employing two crystals which have identical frequency characteristics and connecting these crystals in parallel with each other in the conventional circuit. Series stabilizing choke coils are placed in each crystal circuit for the purpose of holding both crystals in synchronism should temperature effects tend to change the natural frequency of the respective crystals.

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[10] Taylor U. S. Patent No. 1,581,701—April, 1926.

Taylor also developed a method[11] for obtaining three-phase source of radio frequency by employing three synchronized crystal circuits which feed into a *Y*-connected output circuit.

Among other developments of the Naval Research Laboratory is a means[12] for obtaining a crystal-controlled oscillating circuit which by use of stacked crystals and retuning of plate circuit can be made to generate currents of a frequency which corresponds to that of any crystal employed in the stack.

SUMMARY—A discussion of piezo-electric crystals and the early history of the development of the art has been given.

The development of crystal-controlled vacuum tube oscillators by the Naval Research Laboratory has been outlined and various means of amplifying the output of a crystal-controlled oscillator are cited and the best method is described. This method consists of balancing or neutralizing the various stages of amplification and also observing proper precautions for reducing grid circuit losses by using high values of biasing voltage.

A complete high-power low-frequency crystal controlled transmitter is described and a schematic wiring diagram of circuits employing in this transmitter is shown. Schematic wiring diagram and illustrations of one type of low-power high-frequency transmitter complete the subject matter covered in this paper.

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[11] Taylor U. S. Patent No. 1,584,490—May, 1926.

[12] Taylor U. S. Patent No. 1,578,296—March, 1926.

SIMULTANEOUS PRODUCTION OF A FUNDAMENTAL AND A HARMONIC IN A TUBE GENERATOR*

By
Hoy J. Walls

Assistant Electrical Engineer Bureau of Standards

Methods are available for the transmission and reception of two or more frequencies from a single antenna.[1] The published methods, however, contemplate independent modulation of the several frequencies and require a separate generating tube for each frequency. The method here described involves only a single tube. The application immediately in view was the simultaneous transmission of several standard frequencies; other applications are pointed out below. The work, which was done under the direction of Dr. J. H. Dellinger, was part of the standard frequency transmission program of the Bureau of Standards. The reader should understand clearly that the method is one of multiplex frequency transmission but not of multiplex signal transmission, since there is only a single modulation.

The experiments were made in June, 1924, to determine if it were practicable to operate a radio transmitting set on two or more arbitrarily chosen frequencies simultaneously.[1] The results obtained when operating on two entirely independent frequencies were not as satisfactory as desired, but very good results were obtained when operating on two frequencies, one of which was a harmonic of the other.

The circuit arrangement used is given in Fig. 1. It is similar to the usual "Hartley" circuit but has an additional tuned circuit (L_2C_2) in series with the main tuned circuit (L_1C_1). The antenna circuit is similarly arranged (L_3C_3). It was found that, when the tube was generating a fre-

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* Published by permission of Director, Bureau of Standards.

[1] See "Multiplex Radio Telegraphy and Telephony," by Ryan, Tolmie, and Bach. I. R. E., 8, p. 451; 1920.

* Received by the Editor July 19, 1926.

quency approximately $f_1 \frac{1}{2\pi} \sqrt{L_1C_1}$ and the circuit L_2C_2 were tuned to some harmonic of f_1 that harmonic hf_1 would be materially amplified. The strength of the harmonic could be readily controlled by varying the coupling between L_1C_1 and L_2C_2, this coupling being the portion of L_2 common to both circuits. If the antenna, whose reactance has been adjusted[2] so that it is zero for the two frequencies $f_1$and hf_1, is coupled to the inductance L_1 both frequencies are radiated.

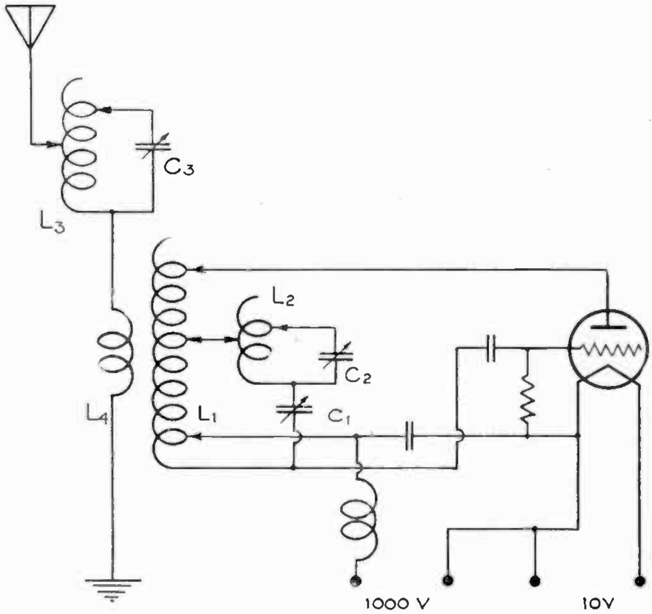

Figure 1—Arrangement for Producing Fundamental and One Harmonic.

Such a tube arrangement, operating on a fundamental frequency of 600 kilocycles with the third harmonic (1800 kc.) strengthened, was coupled to an antenna tuned to 600 and 1800 kc. Good transmission of both frequencies was obtained over short distances. The transmission was not tried over long distances, since a low power tube was used while making the experiments.

Harmonics as high as the tenth (500 kc.) were strengthened with this arrangement when working with a fundamental of 500 kc. Higher harmonics could not be obtained in this case as the limit of the second oscillatory circuit used

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[2] See Bureau of Standards Circular No. 74, pp. 41 to 68.

was slightly over 5000 kc. With a fundamental 2500 kc., harmonics as high as the fifth (12,500 kc.) have been amplified, which was the highest frequency to which the oscillatory circuit used could be tuned. Higher harmonics could probably have been obtained if the oscillatory circuit could have been tuned to higher frequencies. It is to be understood that only one harmonic was amplified at a time. There was no apparent increase in the strength of the other harmonics.

It is evident that the operation of this circuit arrangement depends upon the feedback principle. By inserting the second *LC* circuit in series with the main tuned circuit and tuning the second *LC* circuit to a harmonic, that harmonic would be strengthened somewhat by virtue of the tuning. The then slightly increased harmonic voltage is fed back on the grid of the tube and is amplified, the strength to which the harmonic is amplified being dependent upon the coupling between the main circuit and the second *LC* circuit.

There are several important applications of this circuit arrangement. In relay broadcasting, the main station transmits the same program on two frequencies by means of two independent sets. One frequency is the regular operating frequency in the broadcasting band and the other a much higher frequency, usually between 2500 and 7500 kilocycles. With the circuit arrangement described here it would be quite possible to transmit two frequencies on the same set with any desired output within the capacity of the set on either frequency. This would result in considerable reduction in operating expenses as well as making an additional transmitting set unnecessary.

In calibrating a wavemeter by the use of generator harmonics a generating set of this type is useful when the wavemeter indicator is not sufficiently sensitive to respond to the weak harmonics of the usual generating set. With a fundamental frequency within the range of the wavemeter, any harmonic or higher frequency can be simultaneously obtained with a strength sufficient to operate the wavemeter directly. By changing the fundamental frequency somewhat a new harmonic will be obtained and an indefinite number of points thus secured. To obtain lower frequencies the generating set is adjusted so that the harmonic amplified is within the range of the wavemeter and the fundamental will give the lower frequency.

DISCUSSION ON REDUCTION OF INTERFERENCE IN BROADCAST RECEPTION (GOLDSMITH)

J. C. Van Horn: The curve of percentages of complaints shown in Figure 10 of the paper under discussion, with its peaks and valleys, seems to me to correspond to what might be called the periods of diminished and normal reception conditions. It is therefore related to the electrical field strength curves of distant stations such as have been described by Dr. Heising in his papers on the measurement of signal strength. I feel sure that if field strength measurements had been made on a distant station (say 1,000 miles from WJZ at Bound Brook) it would have been found that when the field strength was least from distant stations in territory normally served by WJZ, the percentage of complaints was highest. Conversely, when the field strength of distant stations was high, few complaints should have been received.

During the period covered by the actual complaints, the "radio weather" in the Eastern Pennsylvania territory was, I am afraid, very poor. The field strengths from distant stations were so low that radio dealers in the territory in question were at their wits' ends to keep both new customers and existing listeners in a contented frame of mind. The customers complained almost universally that, "the only station that we can hear is WJZ". However, in reality had it not been for the existence of WJZ, very few would have heard any broadcasting at all under such adverse conditions.

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*Received by the Editor October 25, 1926.

AN AUTOMATIC FADING RECORDER*

BY

THEODORE A. SMITH AND GEORGE RODWIN

(Technical and Test Department, Radio Corporation of America.)

A device for automatically recording signal intensities is a most useful piece of modern radio laboratory equipment. The value of this apparatus is at once apparent when long, continuous records of signal strength are desired for fading study or for tests of a similar character. It is almost impossible for one man to take a manual record for periods exceeding one hour, when using the ordinary Shaw instrument. Even for shorter intervals the work of keeping a pointer centered on a meter needle is arduous, imposing considerable strain upon the operator. An automatic recorder may be set and left alone to operate indefinitely. Automatic records are also in general more reliable than manual records as the human element is entirely eliminated.

The power required to operate the galvanometer of a Shaw recorder is 0.45 microwatts. Obviously this limited power is not sufficient to operate any ordinary type of graphic galvanometer except one in which the recording is made by a photographic process. Such an instrument is advantageous in that it may be made to follow very rapid fading, but it is inconvenient to use because the fading cannot be observed visually, as well as expensive to construct and operate.

Some means was therefore sought to increase the power available from an ordinary receiver sufficiently to operate a recording meter with a reasonably wide scale, so that fading variations would be well spread out. The use of a radio frequency amplifier of several stages was considered, but was not attempted because of the difficulties in getting the number of stages necessary, to operate stably.

It was desirable that the fading curves be proportional to the carrier field intensity. If a constant note modula-

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*Received by the Editor, July 30, 1926.

tion could be provided at the transmitter, the resulting audio frequency output of a receiver could be amplified sufficiently to operate a recording milliammeter. However, when fading records are desired, of radio broadcasting stations, constant tone modulation is seldom available, and even if such was the case, the resulting curves would show fading of both carrier and sidebands together. An alternative is to supply the constant note modulation at the receiver and to filter out any other modulation which may have been impressed on the carrier at the transmitting station. An audio frequency power amplifier could then furnish enough energy to operate a relatively insensitive graphic meter.

Such an arrangement was suggested by Mr. Julius Weinberger of this Department, and it has been employed with entirely successful results. Two sets were constructed, one for use on broadcasting frequencies only, the other for covering from 16.6 megacycles to 2 megacycles (18-150 meters) by the use of plug-in coils. With an external oscillator tube, the range of the latter was extended to the band from 300 to 100 kilocycles (1000-3000 meters).

The two sets are similar electrically, each consisting of—a superheterodyne receiver, a 1000-cycle modulator, an audio frequency power amplifier, a 1000-cycle pass filter, a rectifier, and a recording milliammeter. The broadcast receiver is a standard Radiola 28, eight-tube set. The short wave outfit consisting of a Standard six-tube "catacomb" such as is found in the Radiola 25, but with the high-frequency amplifier and oscillator external. A General Radio 1000-cycle hummer furnishes the modulation which is introduced into the grid circuit of the radio frequency tube, as shown in Figure 1. The intermediate frequency amplifier, second detector and two stages of audio frequency amplification are contained in the "catacombs" of the receivers. A parallel circuit tuned to 1000 cycles is placed between the second detector and the first audio amplifier. This has been found quite satisfactory in removing the broadcast modulation to a degree insufficient to operate the recorder. A power stage of audio amplification feeds into a rectifier to which the meter is connected.

The recording milliammeter was furnished by the Esterline-Angus Company and is of the electrodynamometer type. The power required to operate it at full scale with all coils

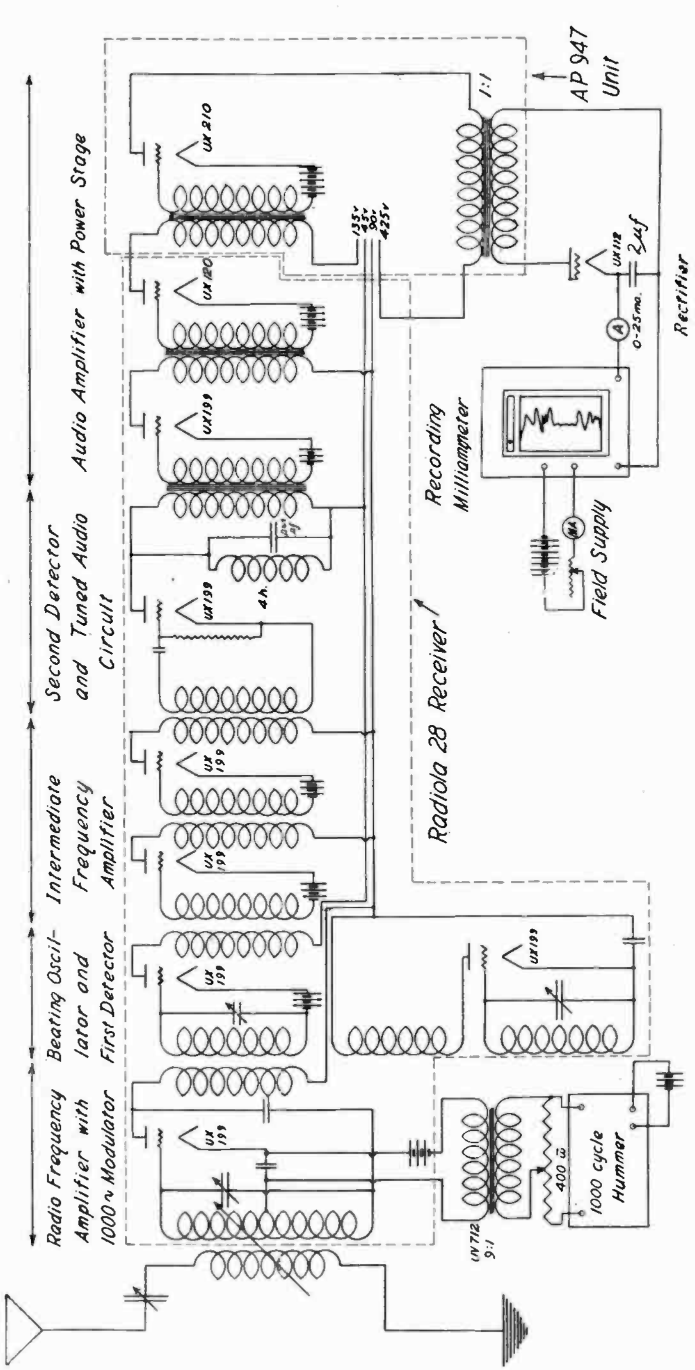
Radio Frequency Amplifier with 1000 ~ Modulator
Beating Oscillator and First Detector
Intermediate Frequency Amplifier
Second Detector and Tuned Audio Circuit
Audio Amplifier with Power Stage
UX 199
UX 199
UX 199
UX 199
UX 199
UX 199
UX 120
UX 210
4 h.
135v
45v
90v
425v
1:1
AP 947 Unit
UX 112
2 μf
Rectifier
A
0-25 ma.
Recording Milliammeter
MA
Field Supply
Radiola 28 Receiver
UX 199
UV 712 9:1
400 ω
1000 cycle Hummer

Figure 1

in series is about three watts. Its resistance under the same conditions is 32, 940 ohms. Full scale current is 10 milliamperes. The meter can be used at record speeds varying from 60 feet (18.3 meters) per hour to ¾ inch (1.9 centimeters) per hour, and thus either short or long-period fading records can be obtained. A second pen marks along the margin of the record and by closing a local circuit, indentation may be made on this trace for the purpose of noting time or disturbances on the record.

With all coils in series, the fading record ordinates were roughly proportional to the fourth power of the field strength owing to the square law action of the detector and the use of a dynamometer type meter. However, as now used, the meter field current is supplied from a local battery and thus the ordinates are proportional to the square of the field strength except at the extreme lower end of the scale. As the record paper is printed with a squared scale, the printed ordinates are proportional to the field strength. This is a convenient arrangement, as the deflections are roughly proportional to the audio output of a receiver.

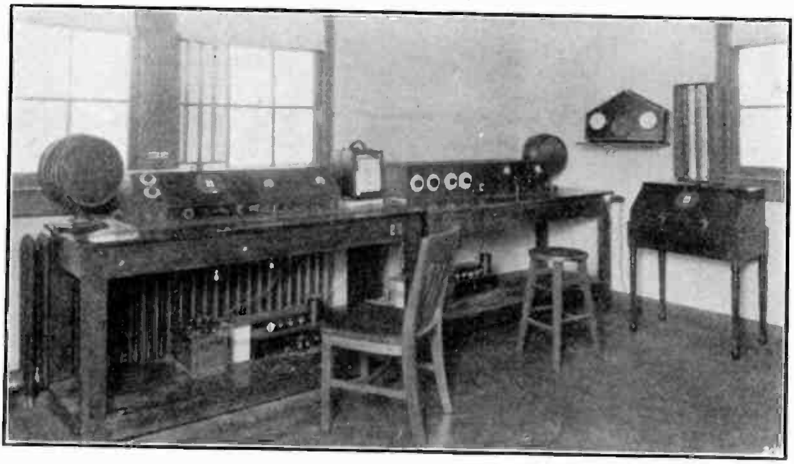

Figure 2—Two Automatic Fading Recorder Sets

The use of direct current in the meter field coils has proved advantageous for changing scales, as by reducing the field current by a known per cent, the deflection of the meter can be reduced in the same ratio. This is a distinct advantage where signals are to be compared or when the signal is fading considerably and it would be difficult to change

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scale in a known proportion by any other means. With one set of coils supplied from a direct-current source, the power required to produce full scale deflection on the meter is reduced to one-half, or about 1.5 watts, which may readily be obtained from a UX210 power tube operated properly.

A six-volt storage battery furnishes the filament supply for all tubes except the power amplifier which is run from alternating current. The B battery current is supplied by the power amplifier unit, shown under the tables in Figure 2.

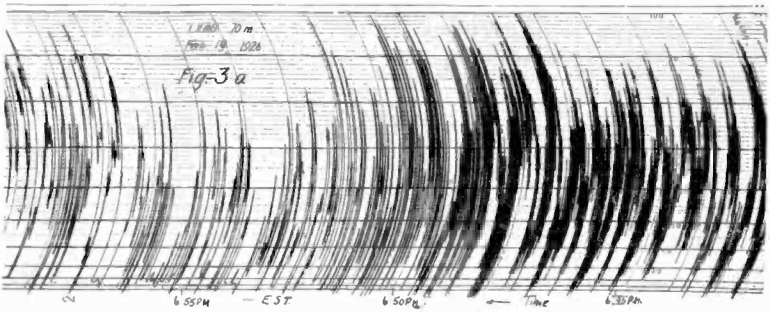

Figure 3a

Provision is made for using a manual recorder in the sets constructed. For measuring field intensities, known radio frequency voltages may be introduced into the input circuit.

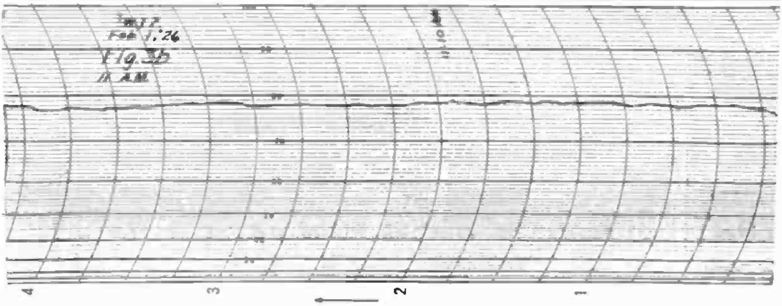

Figure 3b

Sample records taken at various times are shown in Figures 3 and 4. All reception was at the Radio Corporation Technical Building at Van Cortlandt Park, New York City. Figure 3a is a portion of a continuous record taken in the evening of February 19, 1926 of station 1XAO located at Belfast Maine, transmitting on 70 meters. (Belfast is located 350 miles or 560 kilometers from New York City). This record shows the sudden change in period fading sometimes encountered on short waves. Figure 3b is a daylight record of WJZ at Bound Brook, New Jersey, transmitting on 454.3 meters (660 kilocycles).

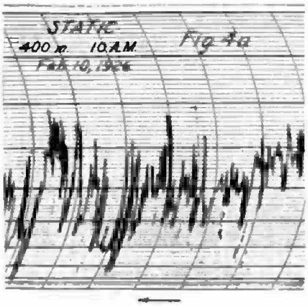

Figure 4a

Figure 4a is a record of static on a wavelength of 400

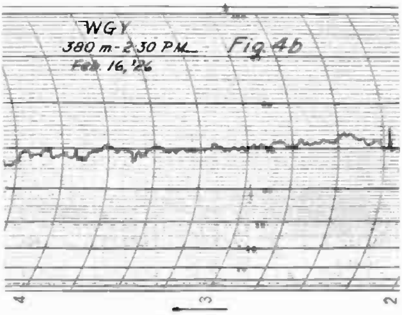

Figure 4b

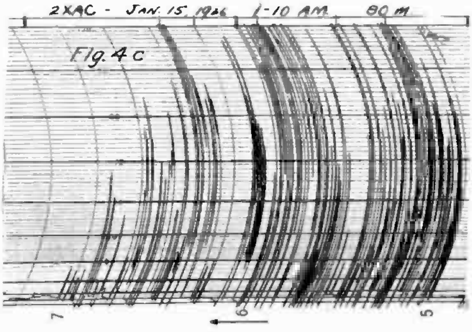

Figure 4c

meters (750 kilocycles) during a snow storm on February 10, 1926 at 10 A. M. Figure 4b shows fading encountered in New York City from WGY in Schenectady in daylight on 380 meters (790 kilocycles). The record in 4c is of short wave transmission on 80 meters (3750 kilocycles) from Schenectady, also in daylight. Figure 4d is transmission from Pittsburgh on 63 meters (4760 kilocycles) at night.

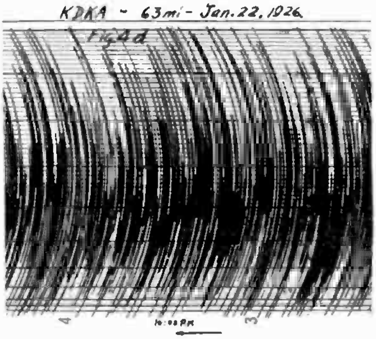

Figure 4d

SUMMARY—A device for automatically recording signal intensities is described with the method employed to amplify the signal sufficiently to operate a commercial type of graphic meter. Sample fading records of various transmissions are presented.

BEHAVIOR OF ALKALI VAPOR DETECTOR TUBES[*]

By

HUGH A. BROWN AND CHAS. T. KNIPP

(University of Illinois)

I—INTRODUCTION

Since the original investigation of certain alkali vapor tubes used as detectors[†] was completed, new and more sensitive types of tubes have been developed and put on the market. Interest has centered around the comparative efficacy of the later tubes with the supersensitive (potassium sodium alloy) tubes previously developed. It is the intention of this paper to point out not only the actual comparisons, but also the manner in which the comparative tests were made. In the past, erroneous interpretation of comparative results have often occurred, due to variations in the manner of conducting tests.

Some very peculiar and interesting features of behavior of the alkali tubes will also be described and illustrated. (These unique features will probably be the ultimate basis for a scientific explanation of the physical phenomena occurring within tubes of this type.) The observations are confined to tungsten filament tubes into which the molecular alloy of potassium and sodium has been distilled at a temperature of 250 deg. cent. by the oil bath described in Bulletin 138[‡]. This particular treatment seems to yield finer results in detection than any other single alkali metal vapor content. A few observations were also made of the effect of forcing sodium through the glass walls, this latter treatment yielding no sensitive detection performance whatever.

II—TRANSIENT PLATE CURRENT VARIATIONS

In order to produce a sensitive potassium sodium alloy content detector it is essential to use a tungsten filament

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[*] Received by the Editor September 7, 1926. Presented at the I. R. E. Convention. New York, January 11, 1927, 10:00 A. M. Session.

[†] See Bulletin 147, Eng. Exp. tSa., University of Illinois.

[‡] See Bulletin No. 138, Univ. of Ill., Eng. Exp. Sta., also Proc. I. R. E. Vol. 10, No. 6, p. 451.

carrying 0.7 to 1.0 ampere which will produce sufficient heat to make the tube walls fairly warm, say 40 deg. cent. on the outside. The tube is not stable in its action until the tube envelope gets hot, and this occurs in about one minute after the filament current is turned on. As soon as the tube begins to warm up the plate current rises, slowly at first, increasing its rate of increase as the tube gets warm; then ceases to rise, and finally decreases to a steady value when the tube walls have warmed up to the final temperature. This phenomenon is shown in Fig. 1. The response of the tube as a detector is rather peculiar and is also indicated on the curve sheet. The peculiar results shown in Fig. 1 do not obtain for any type of high-vacuum tube or gas-content tube now or formerly in general use. Whether or not the tube be well or poorly outgassed when the alloy is introduced, the results are the same in a general way. If there is considerable residual gas the variation is greater as the tube warms up than when the tube is well outgassed, however the writers have not been able to produce tubes which do not show this peculiar quality, and are therefore not able to say whether or not it is due to the presence of residual gas. While the plate current is increasing, a hissing sound occurs in telephone receivers placed in the plate circuit of the tube, the sound increasing in intensity to a maximum, then gradually reducing again until it is not heard when

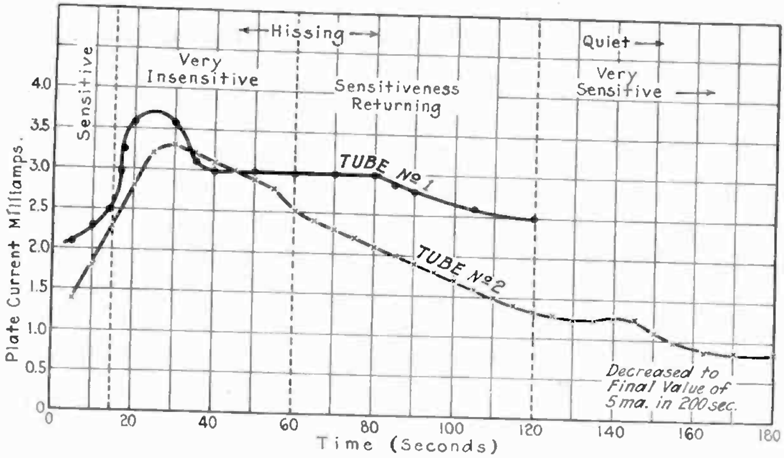


Figure 1

the plate current has reached its steady value. The more "gassy" the tubes the more intense is the hissing sound,

The cause of the variation in plate current detector performance has not been found. It is certain that as these quantities vary the vapor pressure of the alloy within the tubes is increasing until the tube walls reach a final temperature. The increasing vapor pressure in some way affects the behavior noted. The exact mechanism of this, is however not understood at present.

III—PERFORMANCE CHARACTERISTICS

1. *Variation of Response with Plate Voltage, and Input Voltage.* When a high vacuum tube is used as a detector the optimum response will occur at low plate or anode battery potential when the input voltage is very small. When the input voltage is comparatively very large, producing an optimum response having a directly measured audibility of about 150 times, this optimum response occurs at the highest plate voltage that can be provided just below the point where residual gas atoms become ionized. This is usually about 80 to 100 volts for the small amplifier tube now in use. A soft detector tube will not respond at medium plate voltages at all, due to intense ionization. But potassium sodium alloy tubes respond to strong input or signal voltages with increasing intensity as the plate voltage is raised as do high vacuum tubes, even though these tubes contain considerable "inert" gas, as a result of incomplete evacuation. Their response under such conditions is greater than for all other

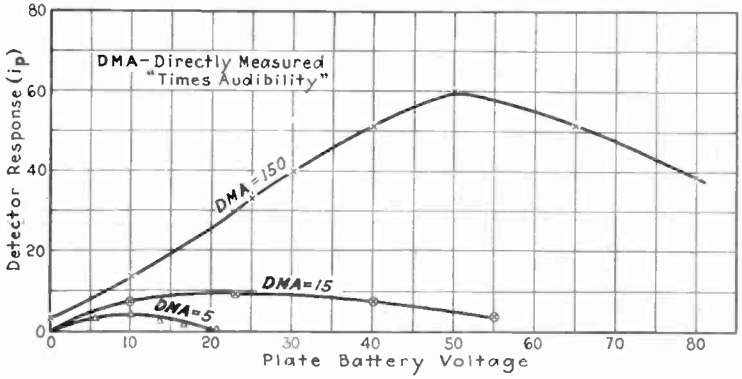


Figure 2

commercial tubes tested except for the UX—200—A. This will be discussed later.

The behavior of a potassium sodium alloy detector under conditions of strong and weak signal voltages is shown in Fig. 2. This property is also possessed by the conventional high-vacuum detector-amplifier tube. The condition of low optimum plate voltage is obtained for a much weaker signal voltage in the case of a potassium sodium alloy tube than for the conventional high-vacuum type. This is illustrated in

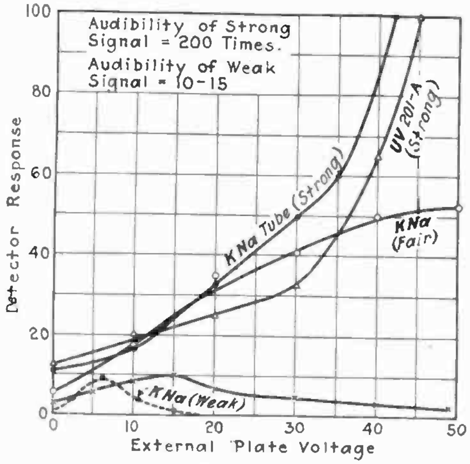


Figure 3

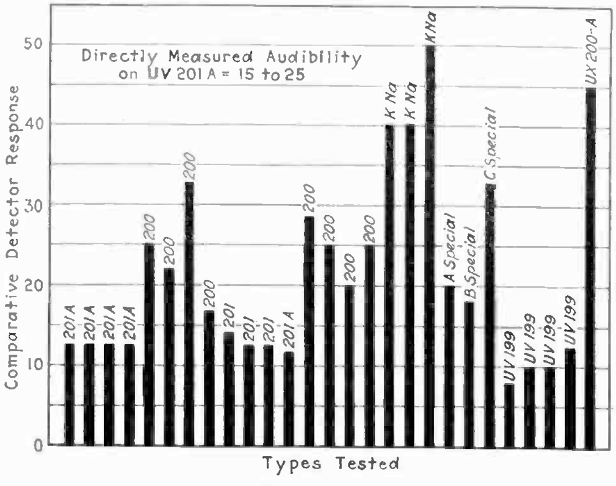


Figure 4

Fig. 3. Not only is the potassium sodium alloy tube a more efficient detector at low plate potentials and low signal voltages, but it is also a more efficient one at high plate potentials (40 to 50 volts) and strong signal voltages. The comparison is made using the optimum plate voltages for the conditions of a strong and weak signal voltages, according to the curves of Figs. 2 and 3.

2. *Comparative Efficiencies.* Fig 4. shows the results of comparative tests on various typical tubes to illustrate the present comparative efficiency of the potassium sodium alloy detector. Since making this test the Radiotron UX—200—A has been put on the market and one typical comparison is added, showing it to be about as efficient as the potassium sodium type, but requiring optimum plate voltages of 40 to 50 as compared with 10 to 20 volts for the potassium sodium tubes on weak signal voltages. For strong signal voltages also higher plate voltages are required for the same degree of response as the potassium sodium tubes give.

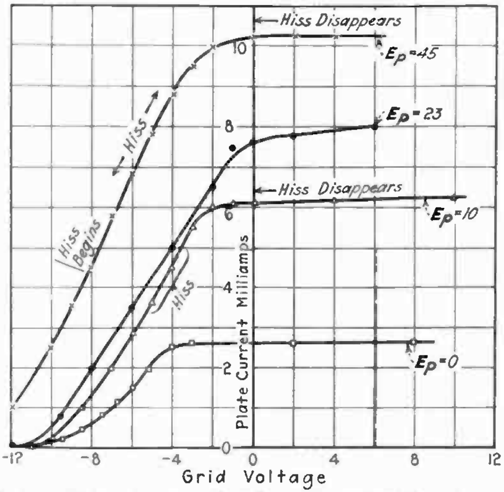


Figure 5—K Na Tube 1924—Showing Peculiarities in Characteristic Curves for Tube Two Years Old

3. *"Hard" and "Soft" Tube Peculiarities.* Attention is again called to the fact that increasing the filament temperature gives the "gassy" potassium sodium alloy tube characteristics of a high vacuum amplifier (See Bulletin 138 loc. cit.). This is especially true of the shape of the characteristic curves of such tubes also illustrated in the

bulletin referred to. As a matter of interest Fig. 5 is given showing how a potassium sodium alloy tube behaves during the change in grid potential indicated by the abscissa of the curves. While the data taking operation is proceeding a hissing sound occurs in phones in the plate circuit, then the ranges of E_g indicated, as if ionization were setting in, but the curves are not "kinky" as those of gas content tubes, and for higher values toward $(+E_g)$ the hissing ceases. This tube in use gives both the sensitive detector performance on weak and strong signal voltages, and the efficient amplification of strong amplifier input voltages. In either service it is a considerable improvement over the same tube not primed with the alloy. The degree of rise and fall of plate current during the warming up process and the attendant hissing noise were decreased by more thoroughly outgassing the electrodes with the aid of a high frequency induction furnace. However, such tubes were seemingly just as sensitive as those which were more "gassy." The transient plate current characteristic shown in Fig. 1 could not be eliminated by heat treatment and long continued evacuation, hence it seems that the transient "warming up" current and hissing is due to increasing activity of the alloy molecules as the alloy vapor pressure increases.

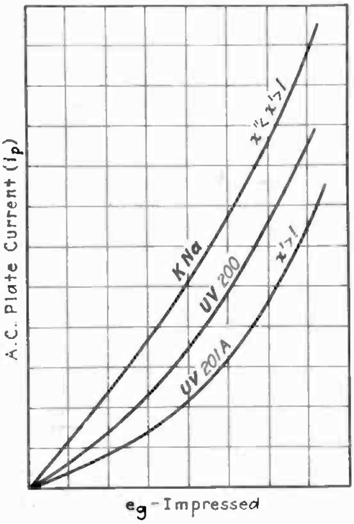


Figure 6

IV—"SQUARE LAW" VARIATION

It has been generally assumed that thermionic tube detectors obey a "square law" relation, that is, the a-c. component of plate current i_p is: $i_p = K\ (e_g)^2$ where e_g is the impressed or signal voltage on the grid circuit. In general $i_p = K(e_g)_x$ and for potassium sodium alloy tubes repeated variations showed that x is more nearly unity than for either "soft" or "hard" detectors. This is illustrated in Fig. 6. This should mean quite an improvement in reception of radiotelephone currents, as it would give more nearly the desired condition of the ideal linear rectifier.*

V—CONCLUSION

Further work has shown that alkali vapor detector tubes, especially those containing the molecular alloy of potassium and sodium, are ideal tubes for durability, true tone reproduction and non-critical adjustment of plate and filament voltages.

DISCUSSION OF A METHOD FOR MAXIMIZATION IN CIRCUIT CALCULATIONS (ROBERTS)

O. C. Roos: Mr. Roberts' interesting paper illustrates a well known theorem concerning the "Hodograph" of Sir Wm. Rowan Hamilton—the discoverer of quarternions.

The Hodograph is simply a polar curve of velocities, which is capable of being divorced from all "imaginaries" for the sake of graphical or mechanical analysis, using the parallelogram of velocities.

"Maximization" of velocities and hence of all other functions changing with time can by its use, be rendered perhaps physically clearer than is possible by the use of imaginaries, as I shall attempt to explain and illustrate below. But first a word on the Hodograph itself is necessary.

In Fig. 1*a* is shown the path of a particle which travels from point *a* to point *g* along the curve *a b c d e f g*. Its velocity at each of these points is given in magnitude and direction by the arrows *a*-1, *b*-2, *c*-3, *d*-4, *e*-5, *f*-6, *g*-7.

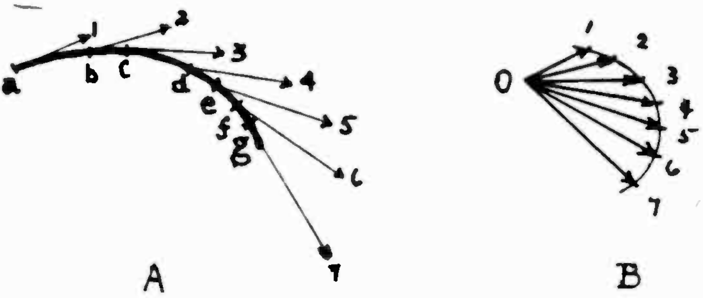


Figure 1

If we now collect all these arrows as vectors with their initial points at *O* in Fig. 1*B*, keeping their directions unchanged, we have the Hodograph 1-2-3-4-5-6-7, whose sectors 1-2, 2-3, etc. 6-7 are a measure of the change of velocities of the particle as it passes between the corresponding points *a*-*b*, *b*-*c*, etc. *f*-*g*, in Fig. 1*a*.

In the limit, the Hodograph is a smooth curve and the velocity at the end of the arrow (vector) from O as it passes from points 1 to 7 is an instantaneous measure of the direction and magnitude of the velocity change, i. e. the acceleration.

Now the applicability of the Hodograph to Mr. Roberts' problem has long been known and is analyzed and applied as follows. The fact is that any monogenic function can be continuously resolved into two components at right angles to each other and its growth in time is proportional to their rate of exchange in time.

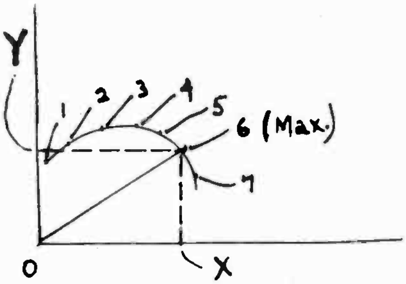


Figure 2—Analysis of Hodograph into Perpendicular Components.

If we turn Fig. 1*b* around and redraw it in Fig. 3, as a polar curve 1-2-3-4-5-6-7, which is z, a function of ox (real) and oy (imaginary) we may consider both ox and oy as dependent variables, both being functions of time. Hence we may consider them as velocities.

Let us postulate that the velocity at 06 is a maximum. Hence the next elementary change in velocity 6-7 must be right angles to 0-6 and measures the acceleration of this maximum velocity. Then in Fig. 3 we decompose the velocity 06 into an X-component OX corresponding to energy cyclically consumed, and into a Y-component OY, corresponding to energy cyclically stored.

We now can lay off a shorter "maximum" velocity OX along 06, making OX^1 equal to OX. It is now obvious that the relative acceleration of OX^1 is the same as 06, since the relative accelerations, 6-7 and X^1—8^1 are the same. Hence the X-component, if it has been changing with time, must not change toward or away from R, but the acceleration must be at right angles to OR, from X, i.e. it must equal X—9 which equals X—8.

Thus the X component is "stationary" or its rate of change or acceleration is zero when X is the variable. A similar argument shows that the Y-component must be "stationary" when Y is the variable.

Of course the device of considering a physical quantity like an impedance, as a velocity, has *a priori* no real justification. It is just a convenience. However, we have the coincidence that impedances in the A. E. M. system are velocities, an ohm being 10^9 cm. per sec. whether wattful or wattless.

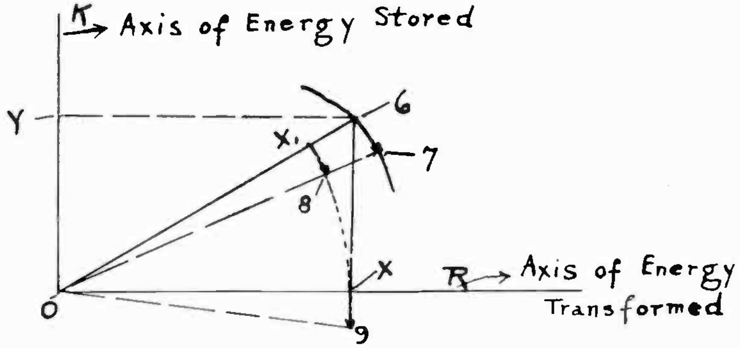


Figure 3—Decomposition of Physical Acceleration into Wattful and Wattless Components.

For those who are not familiar with vectors the Hodograph is thus an aid to physical visualization of a polar maximum.

REPORT CONCERNING THE OBSERVATION OF THE INFLUENCE ON THE PROPAGATION OF RADIO-WAVES OF THE SUN ECLIPSE OF THE 14th OF JANUARY 1925 IN THE DUTCH EAST INDIES

By

E. C. Holtzappel

In order to observe the influence on the propagation of radio-waves of the sun eclipse of the 14th of January this year, which lasted at Weltevreden (Batavia) from 0603 G. M. T. till 0844 G. M. T., the wireless stations at Malabar (PKX on 15.6 km., ANA on 7.7= km. wave) and Tjililin (ANF on 30=Meter wave) both near Bandoeng (Java)—PKX and ANA at about 26 km. south, and ANF at about 18 km. west from Bandoeng—were ordered to transmit simultaneously on the 13th, 14th and 15th signals on 15.600, 7700 and 30 meters during the period 0300 G. M. T. till 10.00 G. M. T.

The first wave was used by the 2400=kw. Poulsen arc (PKX), the second by the high frequency alternator of 800=kw. (ANA) and the third by a 5=kw. short-wave transmitter at Tjililin (ANF).

The foreign stations at Tananarive (Madagascar), Guam (Pacific), Cavite (Philippines) and Saigon (French Indo-China) were asked to listen in to those signals and to report the results and if possible transmit themselves during the time of the eclipse for observation at Bandoeng.

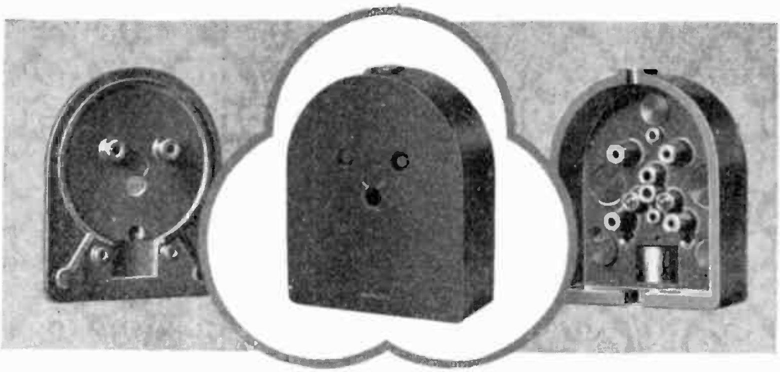
Further orders were given to listen in to the stations in these Colonies at Sabang, Padang, Bengkalis, Palembang and Sitoebondo, whereas our station of Bengkalis was asked to transmit on her Poulsen arc of 6 kw. on 1650 meter wave; furthermore the private stations at Tarakan and on board ships were requested to observe the Bandoeng signals. Signals of different stations were observed at our receiving posts at Rantja-ekek and Padalarang, both near Bandoeng and belonging to the Malabar system.

General results of these observations have been negative as was anticipated, that is, the observed influence of the eclipse on the propagation of radio signals has been almost inperceptible or did not exist at all.

For the stations at a great distance from the track of the eclipse shadow on earth this could be expected, but even at Palembang and Tarakan, lying directly in this track, nothing has been observed of any such influence.

The only exceptions were observed at Rantja-ekek with regard to the signals of Tananarive on 15600 m. and of Bengkalis on 1650 m. which were actually weaker during the eclipse.

On the contrary the signals of Saigon at Rantja-ekek, and the Malabar signals at Sitoebondo during that period were much stronger than ordinarilly which indicates reflection from the shadow zone.



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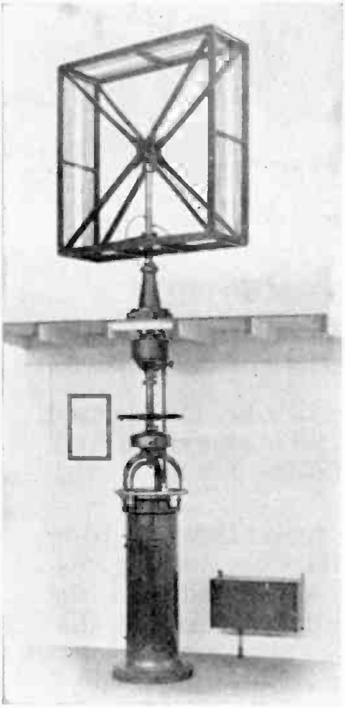

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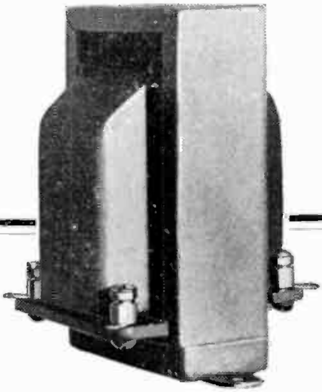

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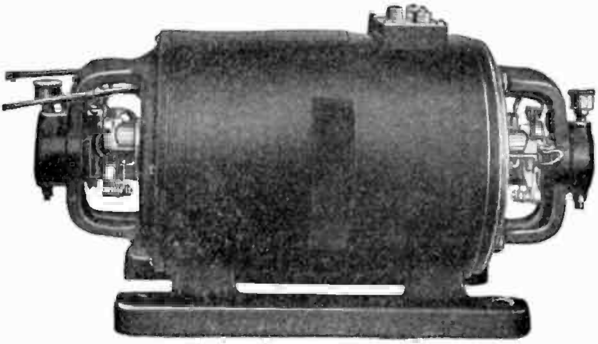

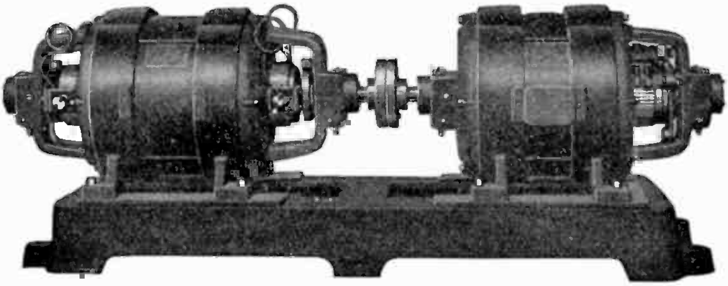

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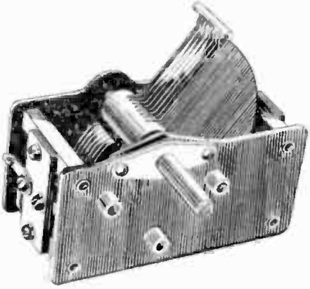

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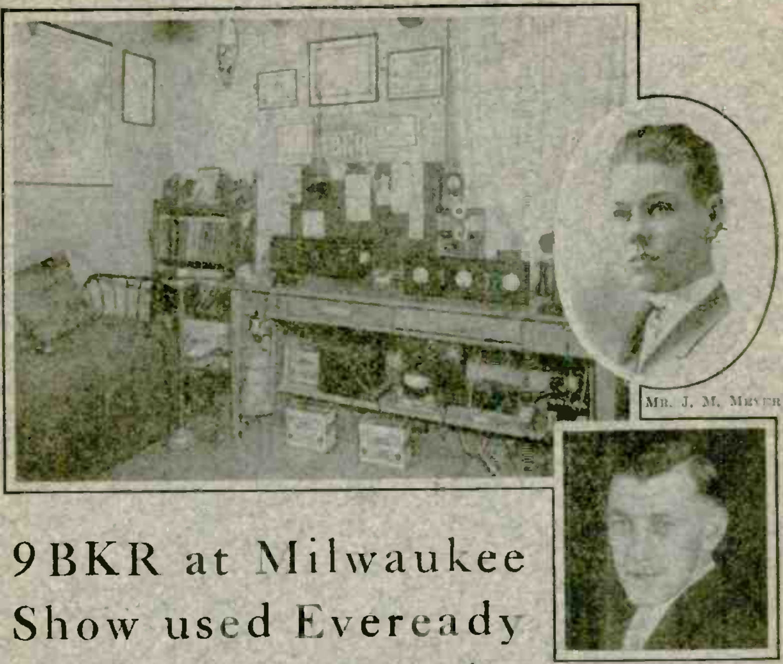

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