The General Radio Experimenter

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ELECTRON OSCILLATIONS

By EDUARD KARPLUS*

WITH regular three-element tubes, oscillations of about 3 meters can be produced without great difficulty. Most of the tubes would oscillate at still higher frequencies, but the output is decreased rapidly. It has been possible to produce oscillations as low as 0.5 meter with special tubes, but these have been only laboratory experiments. One of the difficulties in making a tube oscillate at these high frequencies is the fact that the inter-electrode capacitance of the tube is too high and that it is not possible to build tuned circuits with a high enough impedance. Another difficulty in the circuit is that the time required for the electrons to get from one electrode inside of the tube to another is too long, so that capacitance

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FIGURE 1. An experimental "Barkhausen" transmitter (right) and receiver (left). Mr. Karplus is measuring the wavelength of the receiver with his small reaction-type wavemeter. Two socket adapters are on the table at the right

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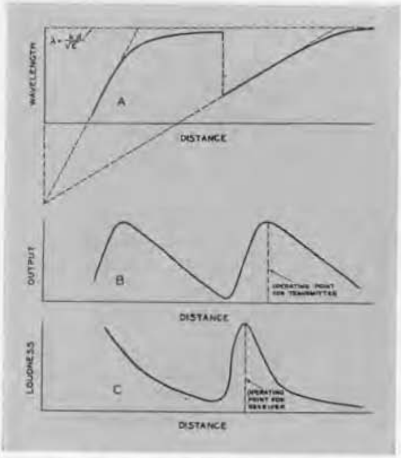

FIGURE 2. Relations between wavelength, power output, and loudness of received signal in an electron oscillator as a function of the "distance" or length of the Lecher wire system

and inductance are no longer the sole frequency-determining elements of the circuit.

An absolutely new method of producing waves in tubes was first described by Barkhausen and Kurz.[1] The frequency of these oscillations is not determined by a tuned circuit, but essentially by the period at which clouds of electrons oscillate in the space between the electrodes of a tube. These are called electron oscillations. The theory of these oscillations is very complicated and the first formula for the wavelength, given by Barkhausen, is only approximately correct.

$$\lambda = \frac{1000\,d}{\sqrt{E}},$$

where λ and d represent wavelength and the distance between electrodes in centimeters, respectively, and E represents the voltage between the electrodes. The formula contains only one distance and one voltage, and, indeed, only two electrodes are necessary to produce electron oscillations. In practical application, however, three-element tubes are used and the third electrode is used to modulate oscillations in a transmitter and to detect oscillations in a receiver. Contrary to the first theory, Gill and Morrell[2] have shown that outside connections to the tube influence the frequency to some extent. A more recent analysis of these oscillations has been given, for instance, by Hollmann.[3]

Figure 1 shows on the left side a receiver and on the right side an oscillator for electron oscillations. The high-frequency part of both of the instruments consists only of the tube and a few parts immediately connected to it. On both sides of the tube the doublet can be seen at the receiver, and at the oscillator these are the two rods at the right side of the tube. A condenser in the form of a round disc can be moved on these rods. The different dials and instruments shown in the two boxes are necessary to control the voltages applied to the tube. Figure 2 shows schematically in its upper part how the wavelength of an oscillator is changed when the system connected to the tube is changed. In the oscillator shown, that system is changed by sliding the round disc on the two rods which form a system of Lecher wires. It can be seen that by increasing the length of the Lecher wires the wavelength is increased almost linearly at first and then reaches a constant value. Then the wavelength drops suddenly to a smaller value, increases again, and reaches the same constant value as before. That process can be repeated over the whole length of Lecher wires.

[1] *Zeitschrift für Physik*, Vol. 21 (1920), 1.

[2] Gill and Morrell, *Philosophical Magazine*, Vol. 44 (1922), 161 and Vol. 49 (1925), 369.

[3] H. E. Hollmann, *Proceedings of the Institute of Radio Engineers*, Vol. 17, No. 2, February, 1929, 229.

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We have said that the wavelength of electron oscillations depends on the tube, the voltages applied, and to some extent, on the connected system. To decrease the wavelength, the voltage must be increased. The efficiency of an electron oscillator is very small, however, and by increasing the voltage, the losses in the tube are rapidly increased. In a three-element tube, the electrode which is affected to the greatest extent is the grid which has to dissipate all the lost energy. As the grid of standard tubes is not designed for that purpose, the voltage that can be applied is very limited. With most of the standard tubes, waves of about 40 to 50 centimeters can be attained. The UY-227, for instance, can be used with 60 volts on the grid and oscillates then at roughly 70 centimeters. With 8 volts on the grid, two-meter waves can be produced. A tube that can be used at shorter waves is the old CG-1162,[4] for instance, that oscillates at 40 centimeters when 150 volts are applied. Figure 1 shows three different socket adapters so that different tubes can be used in the oscillator. With specially-designed tubes supplied with a much stronger grid, waves of about 5 centimeters have been attained. The energy available in electron oscillators generally would not exceed 0.1 watt.

We mentioned above that quite a satisfactory theory has been established about electron oscillations, but the question of receivers has not yet been solved, at least theoretically. Besides the crystal detector, none of the other receiving methods used at longer waves can be applied for electron oscillations. It is possible, however, to use an electron oscillator quite efficiently as a receiver when an audio amplifier is connected to the plate circuit instead of the microphone used in the transmitter. It has been possible to communicate with telephony over a distance of twenty miles, using almost the same oscillator on both ends as transmitter and receiver. The two lower curves in Figure 2 show the best operating points when an electron oscillator is used as a transmitter or as a receiver.

Figure 1 shows a wavemeter for 0.5 to 1 meter. It can be seen that the whole inductance of the tuned circuit is built of the same piece of metal as the plates of the condenser. The bakelite tube can be used as a handle and is made long to avoid any capacity influence. The wavemeter is direct-reading and calibrated in wavelengths.

Besides scientific research, such as the determination of dielectric constants at high frequencies, heating and changing of different chemicals, and the biological influence on living substances, waves produced by electron oscillations can be very successfully used in communication. The characteristics of these waves roughly between 10 centimeters and 1 meter are straight-line propagation, a very low noise level, the possibility of concentrating energy, and the possibility of modulating with very high frequencies. Most important is the application in the navigation of ships and aircraft. A system very similar to the beacon system, applied in much longer waves, is used to a great extent. The advantage of the short waves, however, is that a great many stations can operate without interference in a small area as the radiation is much more limited to short distances by nearly optical laws and can be concentrated much more effectively with comparatively small reflectors.

[4] These tubes are now becoming scarce, but we believe that some are still available in salvage stocks. — Editor.

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Beat-Frequency Oscillators

By Charles T. Burke*

THE distinguishing characteristic of the beat-frequency type of oscillator is a wide range of output frequency with a small variation in circuit constants. The output of the beat-frequency oscillator is, with proper design, substantially constant in voltage over the range for which the instrument is designed. An instrument of these characteristics has a number of applications in the fields of test and laboratory measuring equipment. It is particularly adapted to making rapid adjustments in apparatus designed to operate over a particular frequency range and in testing such apparatus. In both of these applications the important feature is the ability to make a large percentage change in frequency by the adjustment of a single control.

Figure 1. Main tuning control for the new beat-frequency oscillator

The desirable qualities of the beat-frequency type of oscillator are obtained by the use of two oscillating circuits. In general, one circuit is of fixed frequency while a means is provided for varying the frequency of the second oscillator. The difference, or beat, frequency is detected and amplified to the desired voltage output of the instrument. By proper choice of the operating frequencies of the two component oscillators, any desired range of frequency may be covered with a change in circuit constants within the limits of conventional design of adjustable inductance and capacitance units. The distinction between this feature of the beat-frequency generator and the operation of a vacuum-tube oscillator appears from a comparison of the factors governing the oscillator frequency. In an oscillating circuit the frequency of oscillation is inversely proportional to the square root of the capacitance and the inductance in the circuit, consequently a given percentage change in frequency requires a percentage change in capacitance twice as great. Mechanical requirements of design of condenser units are such that the change in capacitance required to vary the frequency of an oscillating circuit from, say, 10 cps.[1] to 10,000 cps. would require the adjustment of several controls. In the beat-frequency generator, however, a comparatively small percentage change in one of the component oscillators will make a large change in the difference frequency. If the component oscillators operate, for example, at 100 kc., a change of only 10% in frequency is required to cover the range of 0 to 10,000 cps. The corresponding change in capacitance is one that may be accomplished in a single adjusting unit.

Several formidable design problems are encountered in the construction of a commercial beat-frequency oscillator. The very feature which we seek in the instrument, that is, a large frequency variation with a small change in circuit constants, presents a serious obstacle. If the instrument is to be at all satisfactory, the output frequency must be reasonably stable, yet a change as small

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[1] cps. is used for "cycles per second" and kc. for "kilocycles per second" throughout.

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as 0.01% in the frequency of either of the component oscillators at 100 kc. would result in a 10% change in the output frequency at 100 cps. Variations in frequency due to time and temperature variations in the circuit constants will be greater than this under usual conditions. It was at first suggested that the use of a piezo-electric oscillator for the fixed-frequency oscillator of the system would be of benefit in overcoming this trouble. Actually, the use of a piezo-electric oscillator makes matters worse since it eliminates in large measure the possibility of drifts of the two instruments offsetting each other. Frequency changes, for example, due to battery voltage, affect both oscillators alike if they are similarly constructed. The effect on the difference frequency is greatly reduced. As a matter of fact, the beat-frequency type of generator is inherently unstable as to frequency and while skilful design will reduce such variations, the instrument cannot be made to equal the conventional type of oscillator in this respect.

A second deficiency of the beat-frequency type of generator is likely to be impurity of waveform. This may take two forms: the presence of additional frequencies in the output due to beats between harmonics of the component oscillators, and distortion due to tube-circuit characteristics. The former effect can be reduced by means of careful filtering of the detector output and by care in eliminating any coupling between the two oscillators except that which occurs through the detector. The avoidance of distortion due to tube and circuit characteristics depends upon the correct operation of

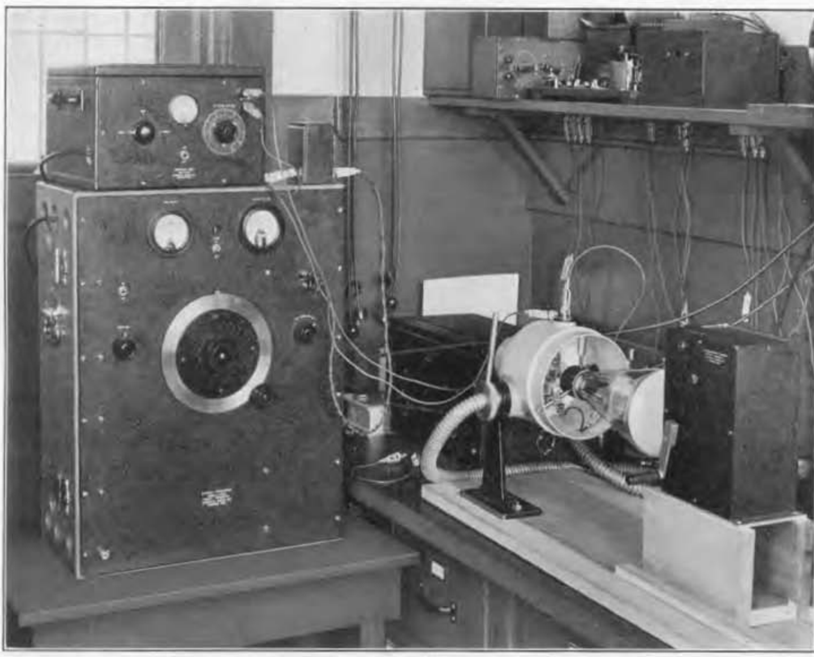

Figure 2. A Type 513-B Beat-Frequency Oscillator being used in development work on the new cathode-ray oscillograph which is soon to be announced

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tubes, at low levels, and the use of linear circuit elements. Circuits containing iron-cored elements are particularly to be avoided.

The illustrations of this article are taken from a commercial design of beat-frequency oscillator which includes a number of rather interesting features which were developed in order to meet the design difficulties confronted in this type of instrument. This beat-frequency oscillator was developed by Messrs. Eastham and Arguimbau of the General Radio Company's Engineering Department.

In order to reduce temperature effects so far as possible, the portions of the circuit most susceptible to such variations have been enclosed in balsa wood compartments. The heat conductivity of this material is extremely low and by its use the circuits are protected from the effects of minor temperature variations. An effort has also been made to equalize the temperature within the unit by the arrangement of the metallic shelving. The tubes are all placed at the side of the instrument, and the important parts of the circuit are enclosed in an aluminum compartment formed by the shelves. The flow of heat through the walls of this compartment tends to equalize the temperature within the cabinet.

With all of these precautions, however, frequency drifts are still present in the oscillator. In order to correct for the effects of such drifts on the instrument, a zero adjustment has been provided. This consists of a small condenser by means of which capacitance can be added to one of the oscillator circuits in order to restore the circuit condition existing when the instrument was calibrated. As a calibration check on the zero adjustment, a vibrating reed is included in the instrument. The natural period of the reed is about 100 cps. and is accurately determined when the instrument is calibrated. The reed setting is then engraved on the main frequency dial. This provides a means by which the calibration of the instrument may be accurately checked at any time.

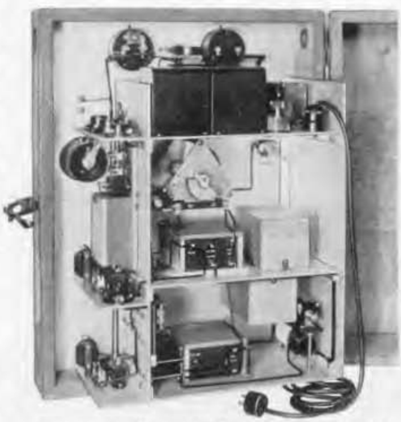

FIGURE 3. Type 513-B Beat-Frequency Oscillator, interior view

The means taken for the elimination of harmonics are not so obvious from the assembly photograph of the instrument. They include the use of filters and the arrangement of parts and wiring. An important feature is the use of toroidal coils in the oscillating circuit. The use of these results in a great reduction in coupling between the oscillating circuits as well as in the stray field of the oscillator itself.

Another interesting feature of this instrument is in the dial. It is desirable to spread the scale as much as possible in order to permit an accurate calibration and an accurate setting to frequency in using the oscillator. A straight-line-frequency condenser with a 270°-rotation has been used and in addition to this a dial of large diameter (8 inches). This combination permits a scale which is open and easily read throughout the range of the instrument.

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WITH the May issue of your Experimenter we enclosed either a card or a letter which we asked you to return if you wished to remain on the mailing list. We take this opportunity of thanking those who have already replied and of reminding the others that we expect to base our mailing list for the June issue on the results of the returned cards and letters. If you received no such notification, please let us know at once, enclosing, if possible, the envelope in which this issue of the Experimenter was mailed. No enclosures were sent to Canadian subscribers or to those whose names were added after April 1, 1931.

* * * *

New Catalog

EARLY this month we mailed to every one of our laboratory-instrument customers a booklet, Part 2 of Catalog F, which lists the new instruments we have developed since last June when Catalog F appeared. If you are entitled to a copy and have not received it, please let us know.

A supplement to our Parts and Accessories Catalog (Bulletin 932) is in preparation and will be mailed out shortly to all holders of this bulletin.

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four-prong tubes either with or without the bayonet lock. The location of the bayonet lock may be shifted to 45 degrees to accommodate the Western Electric Company's E Tube. The TYPE 657 Socket is designed for standard four-prong tubes and the TYPE 658 for standard five-prong tubes. Both sockets have a raised ring around the tube to guide the prongs when inserting the tube.

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