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THE DYNATRON

By CHARLES E. WORTHEN*

A GREAT deal of attention has been given recently to the dynatron type of oscillator. The principle of the dynatron is not a recent discovery, a paper on the characteristics of such a device having been published by Hull† in 1918. The reason for a renewed general interest in the subject is doubtless due to the fact that low-priced receiving tubes with which the dynatron negative resistance characteristics may be easily realized are now available. These are the screen-grid tubes of the 222- and 224-types.

The static $I_p - E_p$ curves of a 224-type tube are given in Figures 1 and 2. In the range of plate voltage which lies roughly between 10 and 40 volts, the plate current decreases as the voltage is increased. This means that the internal plate resistance, which is the reciprocal of the slope of the $I_p - E_p$ curve, is negative, due, of course, to the emission of secondary electrons from the plate. When electrons emitted by the filament reach the plate, the impact releases some electrons from the plate

itself which are immediately attracted away from it by the higher positive potential of the screen grid.

In the dynatron region referred to above, an increase in plate voltage produces a corresponding increase in the number of electrons flowing from filament to plate, but this produces a still greater flow of secondary electrons away from the plate and the net result is a decrease in plate current.

Any device which possesses a negative resistance characteristic will, provided certain other conditions are satisfied, produce self-sustained oscillations. If a parallel tuned circuit is connected as shown in Figure 3 to a tube operating in the negative resistance or dynatron region, oscillations will be produced, provided the impedance of the tuned

circuit (which is closely given by $\frac{L}{CR}$)

is equal to or greater than the negative resistance of the tube. The frequency is then given approximately by $\frac{1}{2\pi\sqrt{LC}}$,

and more exactly by

$$\frac{1}{2\pi\sqrt{LC - \left(\frac{R}{2L} + \frac{1}{2Cr}\right)^2}}$$

where R , L , and C are respectively the resistance, inductance, and capaci-

* Engineering Department, General Radio Company.

† A. W. Hull, "The Dynatron, a Vacuum Tube Possessing Negative Electric Resistance," *Proceedings of the Institute of Radio Engineers*, February, 1918.

[1]



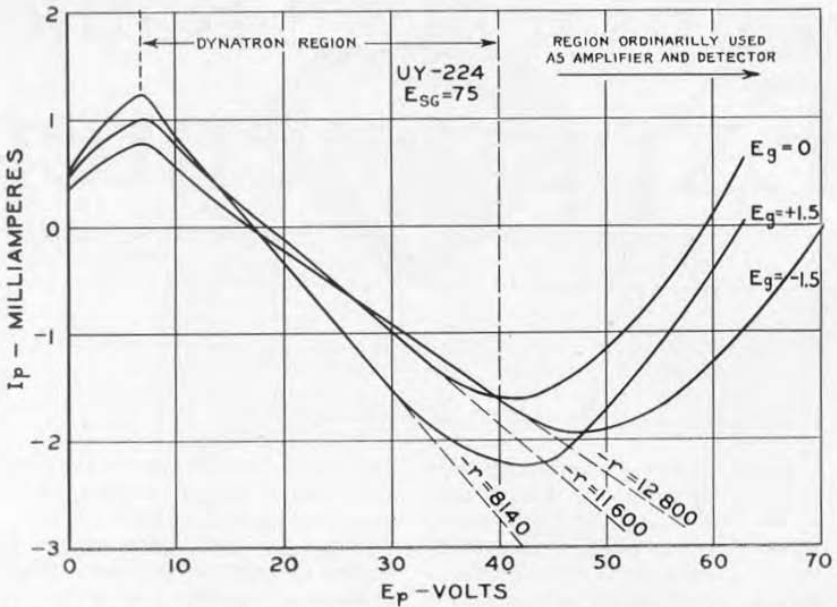
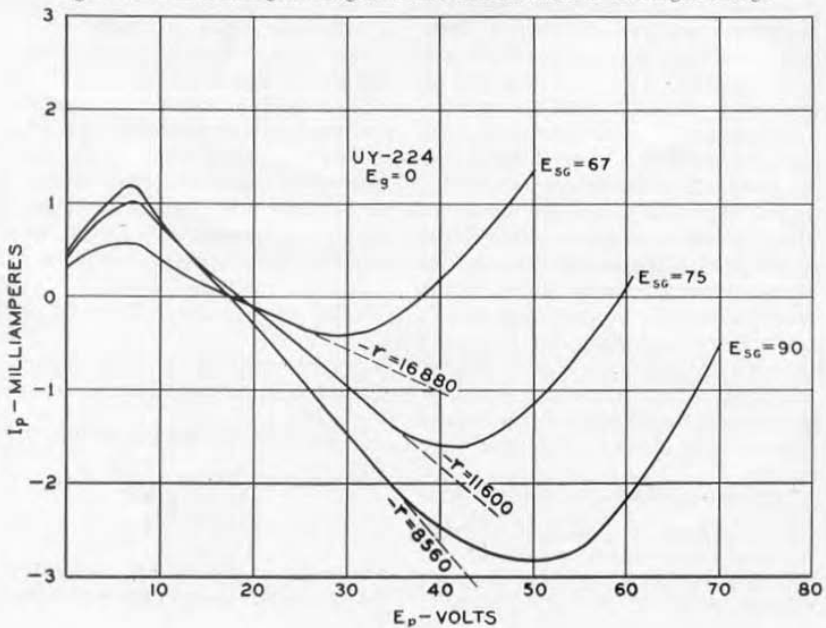


FIGURE 1 (above) — Plate-voltage-plate-current characteristic of a screen-grid tube in the dynatron region with constant screen-grid voltage and three different values of control-grid voltage

FIGURE 2 (below) — Plate-voltage-plate-current characteristic of a screen-grid tube in the dynatron region with fixed control-grid voltage and three different values of screen-grid voltage



tance of the tuned circuit and r is the absolute numerical value of negative resistance of the tube. In all the above expressions, the term C is the total effective capacitance of the tuned circuit which includes the plate-to-filament capacitance of the tube.

The frequency range over which the dynatron oscillator may be made to operate is extremely wide, frequencies from a few cycles per second to some 20,000,000 being obtained by merely changing the tuned circuit. At the very low audio frequencies and the very high radio frequencies care must be taken to keep the resistance of the tuned circuit as low as possible. The point at which oscillations cease is reached when r becomes greater than

$\frac{L}{CR}$. For a given value of negative resistance r and assigned values of L and C (determining the frequency), the value of R will determine whether the system will oscillate. The negative resistance of the tube varies under ordinary conditions from about 8,000 to 16,000 ohms (see Figures 1 and 2)

and in order to produce oscillations, $\frac{L}{CR}$

must lie roughly in this region. If the plate voltage is fixed, the value of the negative resistance decreases with increasing screen-grid voltage and also with increasing positive bias on the control grid. This may be seen from the characteristic curves of Figures 1 and 2.

A convenient way to operate the 224-type of tube is with the control grid tied directly to filament, with 22.5 volts on the plate and 67 to 90 volts (preferably 90) on the screen grid. This allows the use of the ordinary blocks of high-voltage batteries which are tapped at 22.5-volt intervals.

Changes in operating voltages produce a comparatively small change in

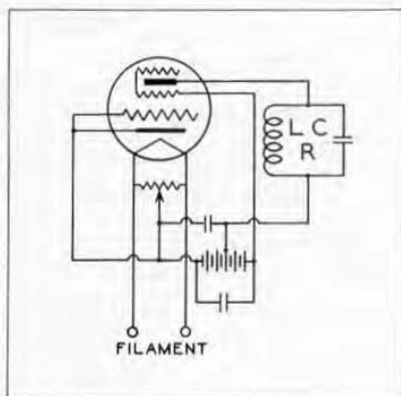


FIGURE 3

frequency. For most purposes, this is entirely negligible. Better frequency stability over an unusually wide range of frequency can be obtained with the dynatron oscillator than is possible with one of the conventional type using a 3-electrode tube. Its stability compares well with that of a piezo-electric crystal oscillator without temperature control. This allows it to be used for fairly precise measurements of frequency, since it can be calibrated against a known standard and will hold its calibration well for long periods of time.

Any resonant circuit wavemeter can be converted into a heterodyne wavemeter by using a dynatron to drive the tuned circuit. Also, the sharpness of indication of the wavemeter can be greatly increased by the use of a dynatron as a means of neutralizing the resistance of its circuit. This can be accomplished by putting sufficient negative bias on the control grid, or by decreasing the screen-grid voltage until the dynatron is just below the point of oscillation. Under this condition, the positive resistance of the wavemeter is largely canceled by the negative resistance of the tube which results in a much sharper resonance

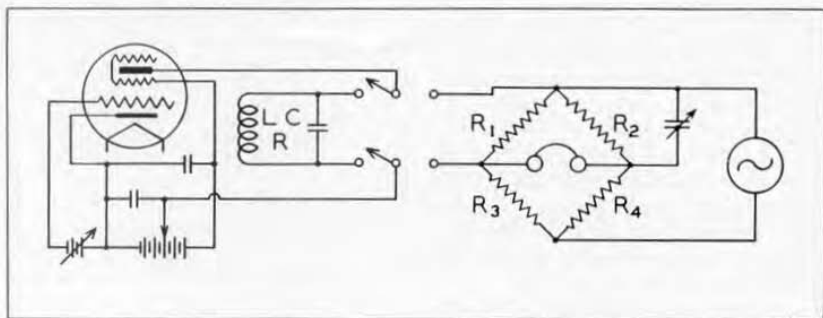


FIGURE 4

peak. When the dynatron is used for this purpose, its plate-current meter can be used for resonance indications.

If a pair of telephone receivers is connected in the screen-grid circuit of the oscillating dynatron, beats can be heard between the dynatron and other oscillators, at harmonics of the dynatron frequency as well as at the fundamental. Harmonics of the order of the fifteenth can be utilized in this way without additional amplification. This makes it possible to use a heterodyne wavemeter which has a limited range of fundamental frequency for calibration work over a much wider frequency range.

In addition to those mentioned above, the dynatron has many other applications. Hull* has described its use as an amplifier and as a detector. It can also be used to measure tuned circuit resistance. If the control grid bias is adjusted until the tube just oscillates, the impedance of the tuned circuit is equal to the negative resistance of the tube and the circuit resistance can be found from the expression

* Op. cit.

$r = \frac{L}{CR}$. The negative tube resistance can be measured in a number of ways. Iinuma† used small positive and negative increments in plate voltage to determine it. Another method which works well uses an impedance bridge, as shown in Figure 4. The tube plate circuit is placed in parallel with a known resistance, the combination forming one arm of the equal-arm bridge. The negative tube resistance is

then given by $r = \frac{R_1 R_2}{R_2 - R_1}$ since $R_3 = R_1$.

Very precise measurement is possible with this arrangement.

The use of the negative resistance characteristic of the dynatron in a resistance-coupled amplifier has been described by Dowling.‡

† Hajime Iinuma, "A Method of Measuring the Radio-Frequency Resistance of an Oscillatory Circuit," *Proceedings of the Institute of Radio Engineers*, March, 1930.

‡ John J. Dowling, "A New Method of Using Resistance Amplification with Screened Grid Valves," *Experimental Wireless & The Wireless Engineer*, Volume V, No. 53, February, 1928.

USES OF POWER-LEVEL INDICATORS

By ARTHUR E. THIESSEN*

THE instrument which indicates the level of power in a telephone transmission circuit is an invaluable device for measuring the performance of the circuit, both while in use and for testing. It is called a power-level indicator, or a volume indicator; more simply, V. I.

When connected across a transmission line carrying a program of voice and music, one of its functions is to indicate to an operator between what approximate power limits the sound is being delivered past its terminals. Speech and orchestral music power vary between wide limits during transmission, but the indicator, not following each sudden variation, reads a mean which is known as the Average Power. Most power-level indicators are simply voltmeters which show the voltage across the transmission line at the point of measurement. The voltage is, of course, a function of the power.†

The measurement of the electrical power in the voice circuit is not difficult once a reference point has been determined. Two levels have been rather arbitrarily chosen as the zero or reference level of power. In some telephone and broadcast circuits, it is taken as 6 milliwatts; for carrier and certain other telephone circuits, it is 10 milliwatts. The choice is quite

* Engineer, General Radio Company.

† The indicator, being a voltmeter, reads proportionally to both the power and the impedance of the line; i.e.

$$E = \sqrt{ZW} \text{ when } W = \text{the power in watts and } Z = \text{the impedance in ohms.}$$

The impedance, Z , of a transmission line is given by the formula:

$$Z = \sqrt{\frac{L}{C}}$$

where L and C are the inductance and capaci-

arbitrary, but 6 milliwatts is the most usual. With this as the standard reference level, power-level indicators are calibrated to read the ratio between the actual power and the reference power in decibels.

One example of the importance of maintaining a check on the signal amplitude of a telephone circuit is illustrated in Figure 1. AA and BB represent 4 electric conductors running close together, as in a cable, for example. In this condition there will be an appreciable amount of capacitance between them. The pair AA is being used for carrying speech originating at the transmitter; while someone is listening to an entirely different conversation on the pair BB . The capacitances between these 4 conductors form the familiar bridge arrangement. If the bridge were balanced, that is, if all of the capacitances were equal, none of the signal in A would appear in B . However, in the majority of actual circuits no such ideal balance is possible and some part of the signal in A is heard in the receivers. It can be found by experience at just what power level this interfering speech becomes troublesome. It is necessary then for an operator to observe the volume level of the speech at the power-level indicator and to hold it below the interfering level by means of the volume control. Besides the difficulty from such crosstalk, a power level which is too high may overload repeaters, amplifiers, or reproducers in the circuit.

ance of an infinite line. In practice, this method works out to be about 500 or 600 ohms. Power-level indicators are usually calibrated on this basis with 6 milliwatts as the reference level. The reference is thus about 1.73 volts.

[5]



On the other hand, there is a very definite level of extraneous noise present in all telephone circuits. Its magnitude depends on a number of factors. On outside telephone lines, interference may be picked up from nearby power lines. Atmospheric electricity affects the lines quite as seriously as it does radio. Poor contacts, generator noise, and microphone hiss all contribute to the unavoidable "noise level" in all voice circuits. In order that speech may be understandable, it is essential that its volume does not fall below the noise level of the system. The power-level indicator provides the means by which an observer can know when the speech power is below the noise level and can correct the condition.

Thus, there are two definite limits between which speech circuits must operate. The value of the power-level indicator is to tell the operator just what the speech power level is, in order that he can intelligently handle the circuit.

Considering the limits of speech power that may be used, there is an interesting analogy between telephone circuits and recording on wax records. Due to infinitesimal irregularities on the surface of the wax, there is always present a certain amount of surface noise or "needle scratch." This is the "noise level" of the wax record. Music

or speech impressed on the record must have an amplitude in excess of this in order to be intelligible. On the other hand, the maximum amplitude is determined by the swing the needle can make without cutting through to the next groove. The usual safe amplitude for records used in talking picture recording is about 0.002 inch. There is danger of cutting over if any greater amplitude is used. This is the overload or "crosstalk" point and the signal must not be allowed to exceed it.

The maximum range between the allowable low and high levels on a wax record is about 36 decibels, a power range of about 4000 to 1. Ordinary speech will never approach this power range, but orchestras, unless especially trained and under the guidance of a careful conductor, will sometimes cover a volume range of 60 decibels, or 1,000,000 to 1. For this reason, the recording level must be carefully monitored and not allowed to exceed the limits defined by the record characteristics. The same is true with the film recording of sound. The maximum level is limited in this case by the width of the sound track, about 0.1 inch.

The use of the volume indicator is not, by any means, limited to monitoring work. It is often used as an aid in equalizing telephone circuits. An ordi-

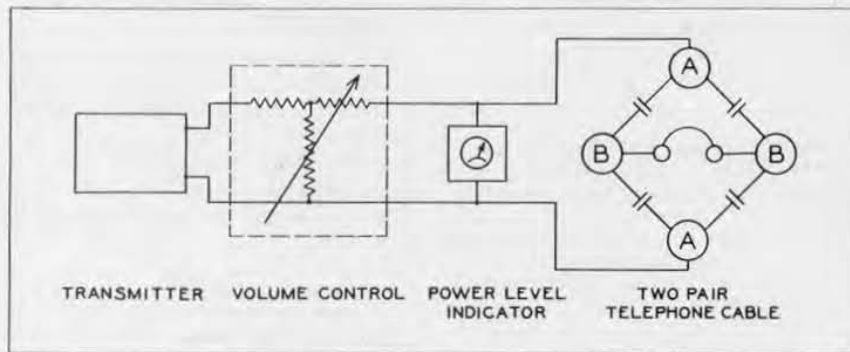


FIGURE 1

nary telephone circuit will transmit certain of the voice frequencies much better than others. For the transmission of speech with fair intelligibility, a frequency spectrum from 200 to 3,000 cycles is needed. But a line that is to be used for high quality transmission of both speech and music, for example, one connecting a broadcasting studio with its transmitting station, must have a flat characteristic from 50 to 5,000 cycles. In order to improve the frequency characteristic of a line so that it may be used for high quality transmission, corrective networks or attenuation equalizers are used. The structure of one of these is shown in Figure 2. The anti-resonant network is tuned to the frequency that it is desired to emphasize. The value of the resistance determines its effectiveness. Several of these networks are sometimes connected across one line and set for various frequencies. To adjust the equalizers, several discrete frequencies from an oscillator are sent, one at a time, into the line at a given amplitude as determined by a power-level indicator. At the receiving end another power-level indicator is connected across the line and the equalizers adjusted until the power level is ap-

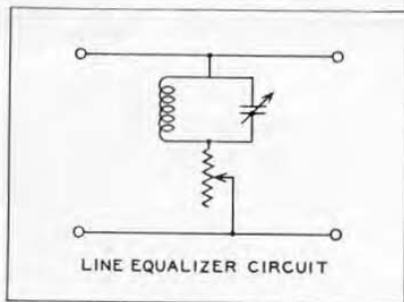


FIGURE 2

proximately the same at all of the test frequencies. When this is done, the engineers are assured that the line has a uniform transmission characteristic over the frequency band.

A gain or loss in power transferred through a network may also be found with some precision by reading the power into and out of the network on the power-level indicator. It is necessary to note that the impedance on both sides of the network being measured is the same. If it is not, the indicator reading must be corrected, because it will, for a given power, read high or low in accordance with the impedance across which it is connected.

EDITOR'S NOTE: The June issue of the *General Radio Experimenter* will commemorate the fifteenth anniversary of the founding of the General Radio Company. On that occasion, the editor steps aside and yields his chair and blue pencil to an anonymous guest, whose identity will forever remain secret.

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