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A tuned plate multivibrator

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The exponential decay of the voltage on a condenser discharging through a resistance has long been used as a stop-watch to measure time intervals beginning at the start of the discharge. Many types of multivibrators[*] employ such "interval timers" in their operation. At very high frequencies, however, precise timing becomes difficult with a simple R-C discharge circuit, and in recent years inductances have been associated with the circuit to enhance the timing accuracy. The radar range unit[†] and the PCM decoder[‡] are examples of this use of inductance with R-C circuits. Pulse durations as small as 0.4 μs were required for the latter system.

In recent experimental studies of time division multiplex systems employing pulse modulation, however, frequencies were required of over 18 mc and pulse durations as short as 0.02 μs—an interval so short that light—which would circle the earth more than seven times in a second—travels less than 20 feet. At these frequencies and pulse durations, inherent limitations of the frequency range of a typical multivibrator circuit restrict its use. It has been generally necessary, therefore, to employ a new type of multivibrator that has a capacitance, an inductance, and a rectifier of the varistor type in its plate circuit.

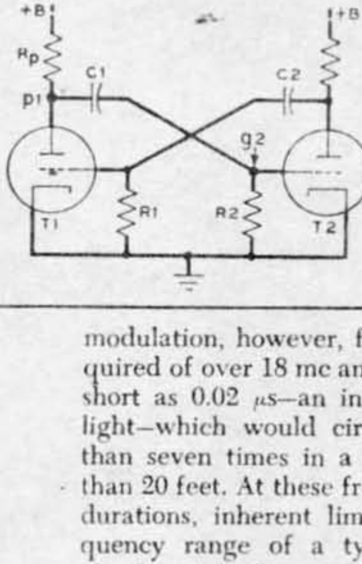

Fig. 1 – Typical arrangement of a multivibrator circuit.

Why the ordinary multivibrator circuit becomes unsatisfactory at such high frequencies will become apparent on a brief analysis of the action of the circuit shown in Figure 1. In this circuit the frequency of oscillation is inversely proportional to the sum of the time constants R1C2 and R2C1, and is also dependent on the tube characteristics, the electrode voltages, and other remaining circuit constants. At higher frequencies, where very small time constants are required, difficulty is encountered in obtaining sufficient amplification to enable the drop in voltage transferred from the plate of one tube to the grid of the other to drive the grid below cutoff.

Suppose, for example, that in order to make R1C2 and R2C1 small enough to produce the desired oscillation frequency, C1 and C2 are each equal to the effective grid-to-cathode capacitance of the tube used. Then only half the voltage developed at the plate of one tube is transmitted to the opposite grid, and twice as much amplification is necessary for multivibrator action at the proper frequency. Unfortunately at oscillation frequencies where the coupling capacitance is necessarily as small as the tube capacitance, a high voltage drop at the plate is difficult to achieve. This difficulty has now been overcome by replacing the plate resistance load of the multivibrator tubes of Figure 1 by a parallel combination of an inductance, a capacitance, and a varistor rectifier as shown in Figure 2. The resulting circuit, although bearing a superficial resemblance to Figure 1 is quite different in performance. Here the frequency of oscillation is determined primarily by the resonance of inductance and capacitance in the plate circuits of the two tubes, hence the name tuned plate multivibrator.

When the grid voltage of a tube having a

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[*] Record, *September*, 1943, *page* 19.
[†] Record, *June*, 1947, *page* 234.
[‡] Record, *November*, 1948, *page* 455.

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capacitance and inductance in parallel in its plate circuit becomes high enough to cause current to flow, the circuit will start to oscillate at its resonant frequency—current in the external circuit starting from zero along the negative lobe of the resonant cycle. At resonance frequency, the impedance of a parallel circuit of inductance and capacitance is high, and thus the amplitude of the voltage wave is large. Since the coupling and grid leak resistances of Figure 2 play no part in determining the frequency of oscillation, they may both be large, thus permitting the large negative voltage developed at the plate to be transferred to the opposite grid with negligible change in either amplitude or shape. Moreover, the timing becomes much more precise.

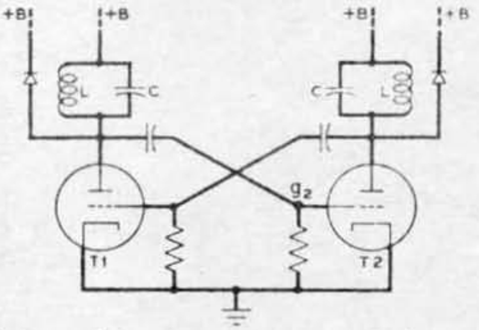

Fig. 2—Typical arrangement of a tuned plate multivibrator.

Assume, for example, that T2 of Figure 1 is conducting and that T1 is not because its grid is below the cutoff voltage. Capacitor C1 will thus be fully charged to voltage B. If the grid voltage of T1 is now raised above cutoff—by means that need not be considered for the moment—T1 will suddenly start to conduct. The resulting current through R_p will instantly drop the voltage at p_1 to some small voltage v_0 equal to the drop across the tube. The terminal of capacitor C1 that had been at potential B will suddenly be lowered by the amount $B-v_0$, and since the voltage across the capacitor cannot change until the charge changes, which requires time, the potential at the other terminal of C1, which had been zero, will drop to $-(B-v_0)$. Since this is well below the cutoff voltage, T2 will at once cease to conduct. At the same instant, C1 will start to discharge, and as it does so the voltage at g_2 will rise toward zero following the exponential curve at the left of Figure 3. When it reaches the cutoff voltage, T2 will start to conduct. This cuts off T1 just as the starting of T1 had cut off T2.

The half period for such a circuit would be from the point t_1 of Figure 3, where tube T2 starts to conduct, to the following corresponding point where tube T1 again starts to conduct. It will be noticed, however, that at these instants, the voltage on the grid is rising slowly, and thus any slight variations in the voltage will make a relatively large change in time. The precision to which the frequency can be held is limited by this fact.

With the circuit of Figure 2, on the other hand, the voltage at g_2 after T1 has started to conduct is as shown at the right of Figure 3. Instead of dropping suddenly and then rising exponentially as in the left-hand diagram, the voltage follows the negative lobe of a steep sine wave. Thus, T2, will be cut off almost instantly and will remain cut off until the voltage again reaches the cutoff value on the rising side of the wave. At this point, however, the curve is very steep, and thus a comparatively large change in the amplitude of the wave will have a comparatively small effect on the time at which cutoff occurs. The timing is thus relatively free from changes caused by variations in tube characteristics or electrode voltages. This is in contrast to the circuit of Figure 1 where transfer is effected at a time which depends greatly on such factors as tube characteristics and electrode voltages.

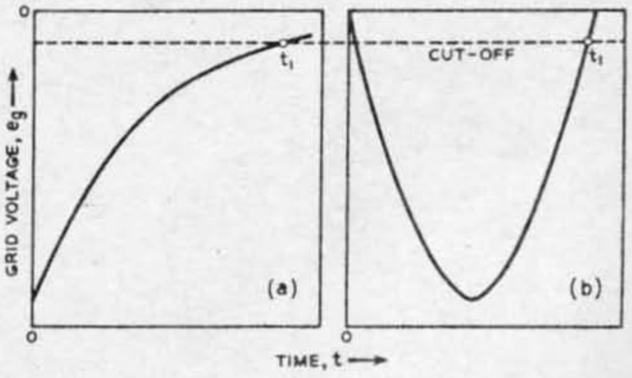

Fig. 3—Plot of voltage at g_2 against time: at the left for the circuit of Fig. 1, and at the right for that of Fig. 2.

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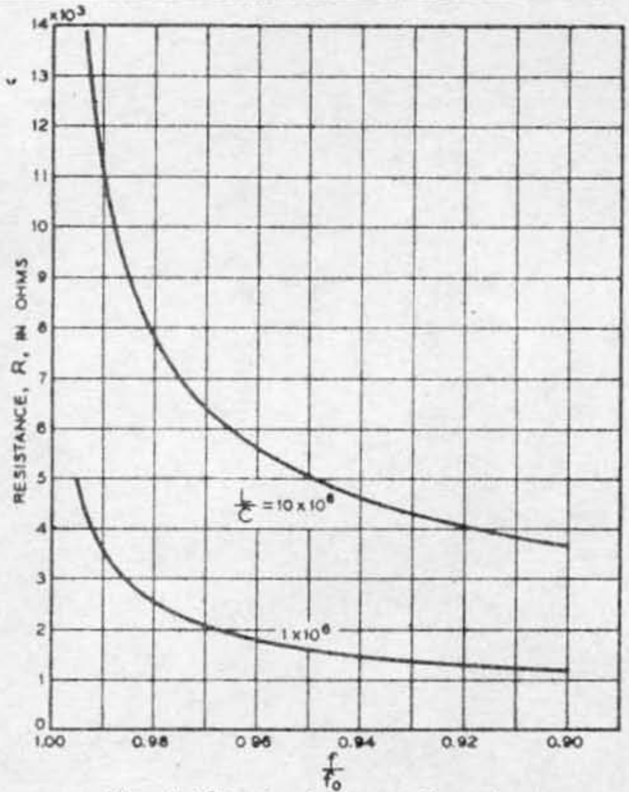

Fig. 4–Plot of R for two values of L/C.

The oscillating frequency of the plate circuit of Figure 2 is given by the expression:

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{1}{4C^2R^2}} \qquad (1)$$

where R is the parallel combination of the tube plate resistance and the resistance of the rectifier. Included in C are the tube and wiring capacitances, while the resistance of coil L is neglected. Oscillation will occur only when R is greater than $\sqrt{L/4C}$. If equation (1) is divided by the resonant frequency of the tuned circuit f_0, where

$$f_0 = \frac{1}{2\pi\sqrt{LC}},$$

the resulting equation becomes:

$$f/f_0 = \sqrt{1 - \frac{L}{C} \cdot \frac{1}{4R^2}} \qquad (2).$$

Plotting R versus f/f_0 for different values of L/C yields curves similar to those of Figure 4. It is apparent here that if R is sufficiently high, the oscillation frequency is relatively independent of R, and is very nearly the resonant frequency of the tuned circuit.

Since R includes the resistance of the varistor, it is not constant. It will be very small when the cathode of the varistor is at a lower potential than its anode and very large when it is at a higher potential. The necessary condition for oscillation is satisfied when both the tube plate resistance and the varistor resistance are high. This occurs each time the tube starts to conduct. At the end of the half cycle oscillation, however, when the voltage of the plate starts to rise above +B, the varistor impedance becomes low, making R less than $\sqrt{L/4C}$, thus placing the circuit in the nonoscillatory condition. Oscillation thus takes place only over the negative half cycle.

This change from the oscillatory to the nonoscillatory state occurs at the time the current in the inductance, and hence its stored energy, is at a maximum value. Before another oscillation can start, a large portion of this stored energy must be dissipated.

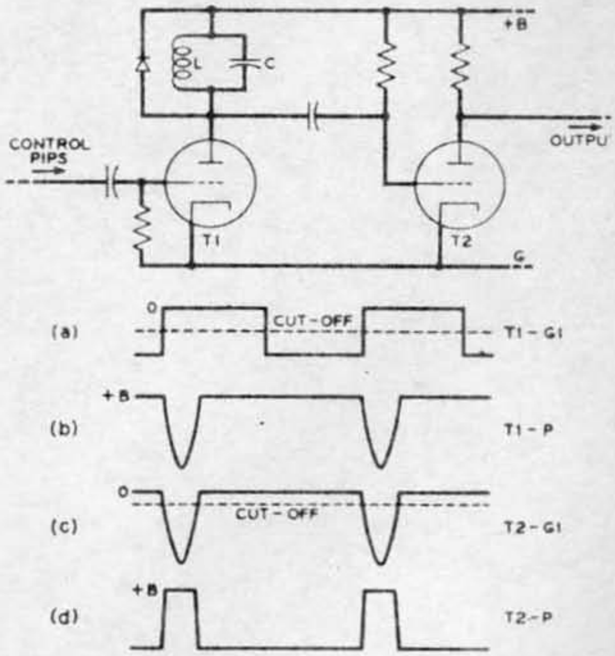

Fig. 5–A basic tuned plate multivibrator circuit, above, and operating voltage graphs, below.

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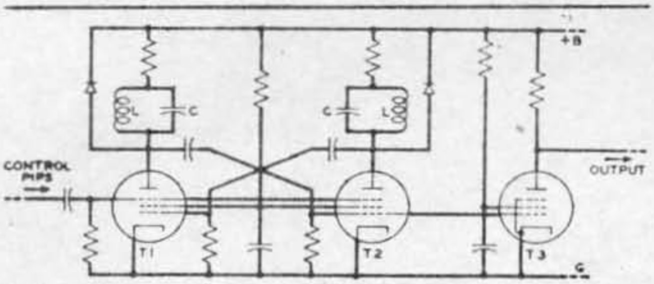

Fig. 6—A tuned plate multivibrator circuit as used to secure frequency division at high frequencies.

Since dissipation takes place in the resistance R over a period of time proportional to L/R, it may be necessary at high repetition rates to accelerate the dissipation of energy by the addition of resistance to the discharge path.

The basic circuit of the multivibrator of Figure 2 consists of a single tube with a tuned plate load. It produces a negative pulse each time the tube is driven from nonconduction to full conduction by a steep wave front. It may thus be used for providing a sequence of short flat-topped pulses by the addition of a tube that inverts the polarity of the pulse and clips off its rounded top. The operation of the circuit, shown in the upper part of Figure 5, is as indicated in the lower part of the diagram. The input to the grid of T1 is a square wave—shown on line (a)—of sufficient amplitude to swing T1 from below cutoff to zero grid. The steep rise in this wave starts the oscillation which lasts for just a half cycle of the sine wave as shown in line (b). This voltage is transferred to the grid of T2 as shown in line (c), thus stopping conduction of T2 for the duration of the pulse and resulting in an output from T2 as shown in line (d). The length of the "on" time of the input square wave is not critical, and may be of longer duration than the output pulse. This is different from the usual single-trip multivibrator where the duration of the tripping pulse is short compared to that of the output. Pulses of very short duration as well as longer ones may be generated in this manner. Using 6AK5 tubes for T1 and T2, an inductance of about 5μH for L, and using tube and wiring capacitances for C, a pulse estimated at 0.02 μs in duration was produced at either 8 or 576 kc.

The spectral analysis of the sequence of pulses of line (b), when the resonant frequency of the tuned plate is high compared to the repetition frequency and is a multiple thereof, shows a fairly even distribution of harmonics of the lower frequency over a wide range. Thus the basic circuit in itself is a very useful harmonic generator which requires no special tuning or shaping of the input wave.

A further modification of the basic circuit results in a multivibrator type circuit very useful in frequency division at high frequencies. This is shown in Figure 6 with explanatory wave form diagrams on Figure 7. It consists of two of the basic circuits cross-connected in typical multivibrator fashion. Pentodes are shown here, instead of triodes, with negative control pips applied to both suppressor grids. A small resistance is added in series with the tuned circuit to provide a load impedance for the control pips and to accelerate the dissipation of energy stored in the inductance. Since the frequency of operation is not determined by the R-C time constant, both the coupling condensers and grid leak resistors may be as large as practical, limited by other considerations such as stray capacity to ground, grid leak bias,

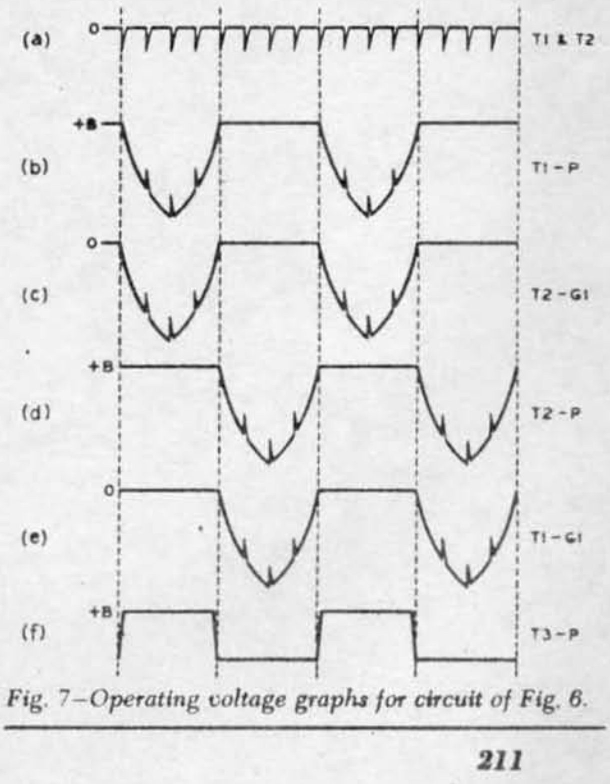

Fig. 7—Operating voltage graphs for circuit of Fig. 6.

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THE AUTHOR: A. E. JOHANSSON joined the Laboratories after graduating from high school in 1929. Beginning as a messenger, he progressed to Technical Assistant and finally to Member of the Technical Staff. He received the degree of B.E.E. from New York University in 1944. As a member of the Transmission Research Department, his work is primarily on multiplex pulse modulation systems. During the war he was concerned with the development of non-linear coils for radar applications.

and the like. The output may be taken from either plate or grid, but is shown as being taken from one grid through T3.

Wave forms are shown for an 8 to 1 stepdown. Line (a), Figure 7, shows sharp negative control pips applied to both suppressor grids. Assume at the beginning of operations T1 is cut off and T2 is conducting. In this condition negative pips on the suppressor grid of T1 have no effect, but the first negative pip on the suppressor of T2 will cut off T2 causing its plate voltage to rise suddenly. This rise is transferred to the grid of T1 causing it to conduct. Then as was previously shown, the voltage at the plate of T1 line (b) will begin to describe a sine wave of frequency determined approximately by LC. This voltage is transferred to the grid of T2 holding it in the cutoff condition. Each time a negative pip appears on the suppressor grid of T1 a positive pip is produced across the small resistor in series with the tuned circuit in the plate of T1, and hence is added to the sine wave being transferred to the grid of T2. These pips are ineffective until the sum of the sine wave voltage and pip voltage on the grid of T2, enters the conducting region of T2. The fifth pip then causes T2 to switch on, and by multivibrator action T1 goes off. The plate voltage of T1 trying to go above +B is restrained by the varistor and held at +B. The process thus repeats with T1 and T2 changing roles at every fourth pip on the suppressor, thus giving an 8 to 1 stepdown. This method was used in the laboratory in stepping down from 18.432 mc to 8 kc in the following steps: 8 to 1 from 18.432 mc to 2.304 mc, 4 to 1 from 2.304 mc to 576 kc, 6 to 1 from 576 kc to 96 kc, and 12 to 1 from 96 kc to 8 kc.

This Month's Cover

With the equipment shown on the front cover, Bell Telephone Laboratories engineers can determine, in less than one working day, what happens to a telephone handset during an average four years of customer usage. Simulating the user's "hanging up" action, the machine drops the handsets once each second until 22,000 drops have been made. Main object of the test is to study the effects of usage on the tiny carbon granules contained in the transmitter. It has also been applied to determine durability of finishes.