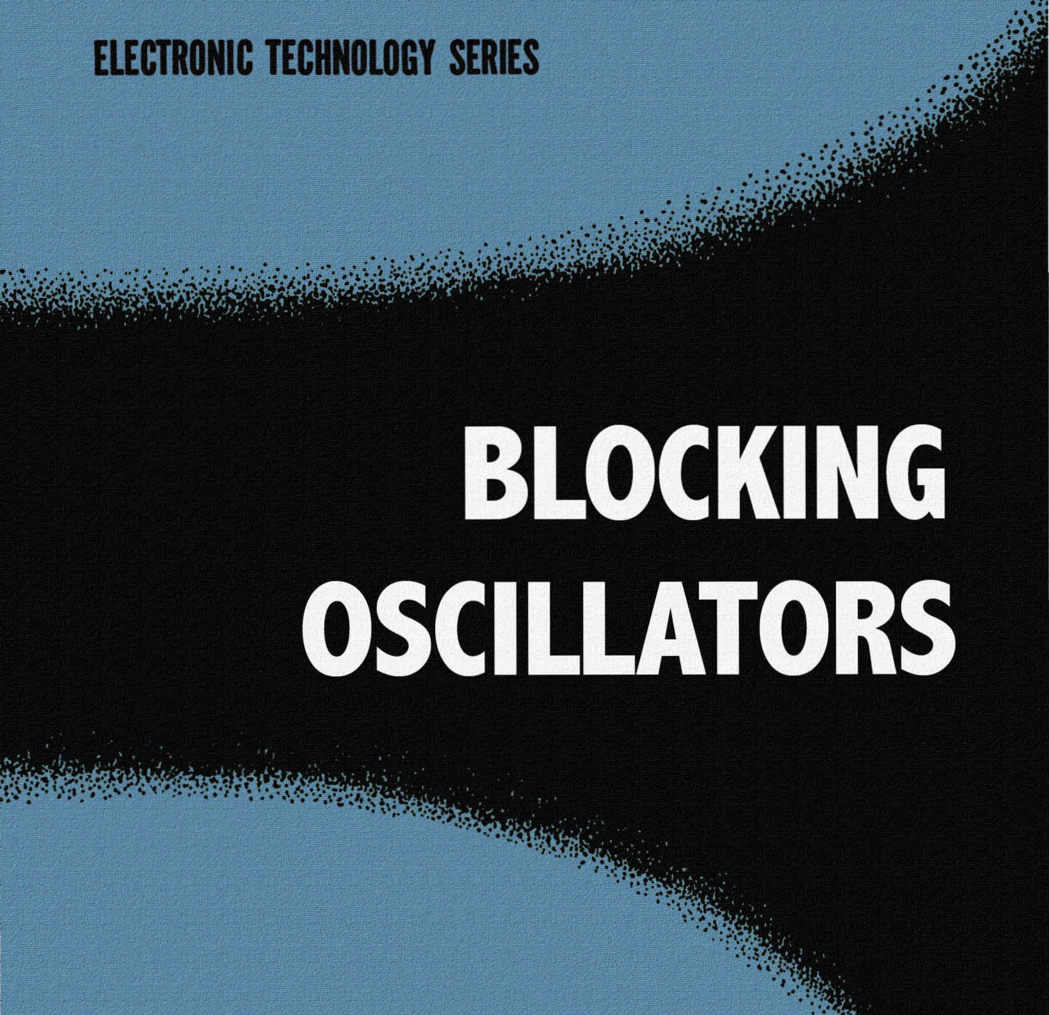
ELECTRONIC TECHNOLOGY SERIES



BLOCKING OSCILLATORS

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BLOCKING OSCILLATORS

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PREFACE

Blocking Oscillators serve a variety of uses in many applications of modern electronic circuitry. As a result of their importance, this text has been written to give a non-mathematical but extremely comprehensive explanation of the operating features, pertinent design factors, and the more important applications of blocking oscillator theory.

The subject matter is organized to give a comprehensive review of the topics presented and to help the technician, advanced student, or practicing engineer develop an understanding of these fundamental concepts to best advantage. Thus particular attention has been given to the role of the transformer, a most essential component often neglected or minimized in many written or verbal explanations of these types of circuits. In the complete analyses of the blocking oscillator, the conventional treatment of the operation of the circuit usually given is summarized and the inadequacies that attach themselves to such a discussion are reviewed in a complete description of the blocking oscillator circuit operation. For example, in addition to the thorough presentation of the blocking oscillator transformer mentioned previously, rigorous qualitative discussions are given of the quiescent interval, conduction due to grid bias, conduction due to regeneration, conduction due to circuit elements, the combined conduction effects, determination of conduction duration, termination of conduction, and shock excited circuits. Thus complete analyses are provided.

Other types of non-sinusoidal oscillators are not covered in detail in this volume, since these are the subjects of another book in this series.

Grateful acknowledgment is made to the staff of the New York Technical Institute for its preparation of the manuscript for this book.

New York, New York A. S.
June 1956

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Chapter 1

DESCRIPTION OF OPERATING FEATURES

Amplifying devices, the most common of which are electron tubes and transistors, have made possible the development of circuits that produce currents and voltages having special recurrent waveforms. As a class, these circuits are called oscillators.

The complete oscillator circuit contains an amplifying device and a wave shaping network. The wave shaping network merely determines the general outline of the output voltage or current waveforms. The amplifying device is used to develop the power fed back to maintain the repeated waveforms. In many types of oscillator, the waveforms approximate sine waves, but in blocking oscillators the output waveform always diverges substantially from that of a sine wave. It is often rectangular or sawtooth in shape with spike-like additions.

Blocking oscillators, in their usual design, are low impedance generators of voltage or current of special waveforms. These voltages or currents are often used to start action in other circuits, a process called *starting* or *triggering*. They are not in themselves precise timing references, because there are wide tolerances in their pulse width, shape, and amplitude. They are affected appreciably by: (a) variations in supply voltages such as their plate "B," grid "C," and filament "A" supplies; (b) features of circuit elements such as the uniform storage of energy in their transformer cores (residual magnetism); and (c) variation of cathode emission, which is very great for minute intervals and requires restabilizing of the cathode surface temperature for repeated exact emission characteristics. Of course, as in all electrical circuits, the timing is affected by variations in temperature. These variations may be internal, ambient or both. Changes in timing may also be caused by the proximity of structural metals or other parts that affect either the physical or electrical characteristics of the oscillator.

The blocking oscillator has an advantage over the gas tube type of timing oscillator in that its recovery time is not dependent upon the time of deionizing of a gas. It outperforms the multivibrator type of timing oscillator in that it consumes power only while conducting, which is, in the usual case, a very short duty interval compared to the total time included in its recurrent waveform period.

Operating power (except to the filament or heater) is usually dc although ac can be used. Blocking oscillators are not very efficient, most of the input power being dissipated in circuit elements. For example, in the oscillators used in receiving apparatus, such as television and radar, the signal output is only a small percentage of the supplied power. In higher-power oscillators, the efficiency can sometimes be made to exceed 50 percent.

Oscillators may be divided into two types: (a) those that produce sine wave or very nearly sine wave outputs, and (b) those that produce outputs having waveforms quite different from that of a sine wave. For the purpose of this discussion we are not concerned with sine wave oscillators.

It should be noted, however, that sine wave oscillators depend upon some form of frequency determining network, such as the tuned circuit used in the Hartley oscillator, or a single frequency-sensitive circuit as in an *R-C* oscillator. Where a transformer is used to feed back energy to maintain oscillation in a sine wave oscillator, it must transfer signals at only a single frequency or at most a narrow band of frequencies. The transformers may therefore be designed to have considerable leakage inductance. As we will explain later, the blocking oscillator transformer does not have appreciable leakage inductance. It does have many other design requirements that transformers in other oscillators do not have.

The sine wave oscillator can be arranged for "squegging" or "quenching." In these conditions the oscillator operates for several cycles before developing the grid bias necessary for halting its operation. The output appears as several sine wave cycles, sometimes decaying in size, then a pause (referred to as the squegging or quenching interval) before the sine waveform again appears. This class of oscillators is sometimes confused with a blocking oscillator. However, it definitely belongs to the sine wave group, because wave shaping is dependent upon a tuned circuit oscillating.

Non-sinusoidal oscillators produce voltages of many different waveforms. They are complex in frequency analysis and do not lend themselves to simple word descriptions as do voltages of sine waveform. They include all of the relaxation types of oscillator, the multivibrators, the sweep circuit arrangements used in oscillographic displays, the thyratron, the phantastron, the flip-flop, and the gas tube oscillators. The blocking oscillators belongs to this category because its output waveform differs widely from that of the sinusoidal type.

An early description of the unique operational features of the circuit that later became known as the blocking oscillator appeared in 1931.[1] The circuit that was studied, together with a few of the waveforms that were presented, is shown in Fig. 1.

In this circuit, the transformer is designed so that the coefficient of coupling equals the mutual inductance divided by the square root of the product of the inductance of each of the two windings. This makes the coupling coefficient substantially equal to one. The R_g resistor has a value of 100 times the turns ratio. It was with these values that the curves shown were obtained. This is the first record of the use or analysis of a blocking oscillator.

As may be seen, the blocking oscillator is a transformer coupled feedback arrangement that appears in schematic form very much like an Armstrong sine wave oscillator. The plate current flows for a short time, a period sometimes erroneously called a "positive half cycle." Actually, the interval during which the plate current flows is a very short portion of the total time of the recurrent waveform, far less than a half cycle.

In synchronized oscillators; the plate conduction period is initiated by a *trigger* voltage pulse, applied to the plate or grid before the conduction would self-initiate in normal "free-running" condition.

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[1] F. Vecchiacci, "Oscillations in the Circuit of a Strongly Damped Triode," *Proc. I.R.E.*, XIX, 856-872.

The positive interval of the tube conduction terminates when the activating power released by the triggering signal has been dissipated. During the time the triggering power is used, the grid capacitance takes a substantial charge, which provides sufficient bias to keep the tube cut off for a longer period than the conducting interval. While the tube is cut off, it is said to be in its "negative half cycle."

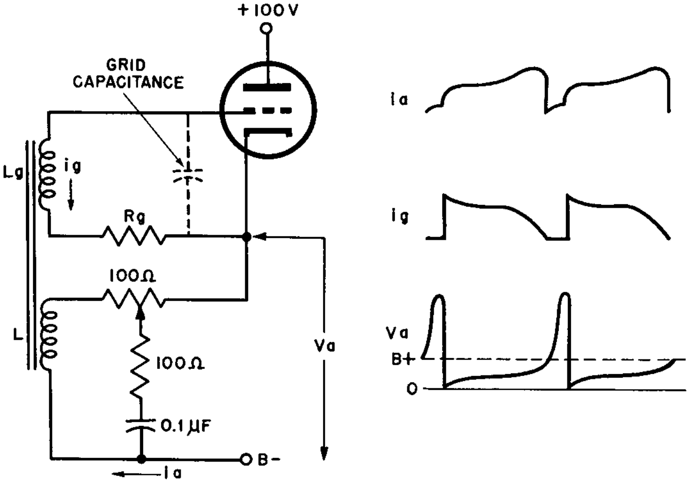


Fig. 1 Vecchiacci oscillator.

These two phases of operation have considerably different time durations, the first (or conducting) period being short, the second (or non-conducting) period being long. The tuned circuit, if it does appear in the circuitry of the blocking oscillator, does not play a role of frequency or recurrence determination as it does in a sine wave oscillator. The transformer used to feed the energy to the grid circuit has little leakage inductance, an important item in its operation, as will be explained later. The negative or non-conducting interval depends very greatly upon the *R-C* time constant, or upon a triggering voltage that causes the negative interval to terminate sooner than it would if the *R-C* time constant were the sole determining factor.

In the common type of blocking oscillator circuit, the wave shape of the positive interval is nearly rectangular. Its output may be a voltage or a current wave, depending upon the manner in which the output circuit is arranged. Its duration is, in a large measure, a function of the constructional features of the feedback transformer. In analyzing the output waveform, attention is drawn to the fact that the blocking oscillator is not a precision device. This means repetitive waveforms are not exactly reproduced each time, and that precision of reproduction is greatly affected by supply voltages, the condition of the tube, and features of the circuit elements, particularly the transformer as it affects the storage of magnetic energy.

The recurrent operation of the blocking oscillator is dependent upon two reasonably controllable factors: transformer design and negative interval design. The oscillator may therefore be made to operate with a fairly stable frequency-waveform relationship. Were this not the case, it would not be feasible to use it in such applications as radar and television, where the sweep lines must start in timed sequence with precision as great as a few millionths of a second.

Most of the responsibility for the accuracy of blocking oscillators in such applications lies in the use of a *triggering voltage* that establishes the moment of recurrence of a certain portion of the oscillator cycle. In the case of the television application, the triggering pulse is developed from a synchronizing voltage delivered by another circuit. In other cases, the trigger is a reflected pulse on a delay line, or even a signal from another oscillator. The circuit arrangements for triggering are many and varied. Some of these arrangements will be discussed in more detail later.

Voltages or currents of any of a number of waveforms may be obtained from a blocking oscillator. The particular form or portion of the waveform of output to be produced is determined by the circuit that is to be controlled. In one television receiver version, the conduction periods actively control the timing, while the intervals between the conduction periods are quiescent. While the tube is in the cutoff state, other components continue to function while awaiting the start of the next conduction "half cycle." When conduction begins, the blocking oscillator takes over control, accurately timing the next sequence of operations.

1. Review Questions

(1) Name at least one way in which blocking oscillators differ from all other types of oscillators.

(2) What are two causes of a change in the repetition rate of a blocking oscillator?

(3) Compare and contrast the blocking oscillator, the gas-tube relaxation oscillator, and the multivibrator with respect to waveform output, stability, and amplitude of output.

(4) Are blocking oscillators efficient? Explain.

(5) Give evidence either to support or to refute the statement that tuned circuits play a part in determining the repetion rates of blocking oscillators.

(6) Does squegging or quenching action enter into the operation of a blocking oscillator? Explain.

(7) Are the negative and positive portions of the wave timing in a blocking oscillator the same? Why?

(8) What role does the feedback transformer have in the timing of a blocking oscillator?

(9) Explain the action of a triggering voltage applied to a blocking oscillator.

(10) What must be done to make recurrent operation reasonably stable?

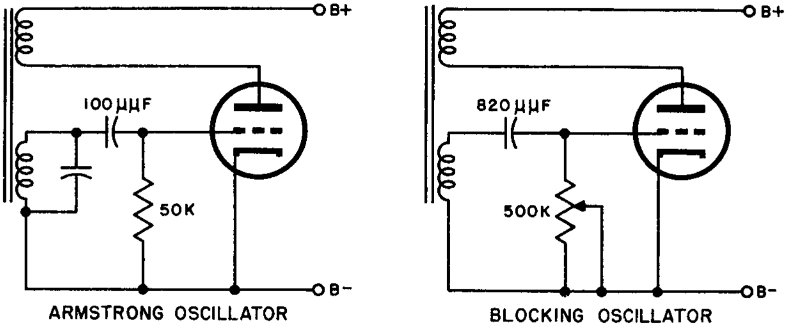
Chapter 2

POPULAR DESCRIPTION OF OPERATION

The usual sine wave oscillator is so commonly used that it becomes easy to confuse its operation with more complex types, such as the blocking oscillator. The marked similarity of the simple form of the blocking oscillator to the Armstrong oscillator can be easily recognized in Fig. 2.

The popular description of operation that follows, although far from precise, does appear in present texts so often that it is given here so that the reader's attention may be called to its inadequacies.

In this discussion the blocking oscillator is considered as an ordinary tuned-grid inductively-coupled oscillator having an inductance-capacitance (*L-C*) ratio not much higher than the square of the value of the internal resistance of a triode plate circuit. The tuned circuit is assumed to have a low decrement (damping factor). The capacitance used to tune the grid inductance consists of the distributed capacitance of the coil and wiring in addition to the tube grid input capacitance. The plate circuit is tightly coupled to the grid coil. The turns ratio is arranged to give a high grid drive compared to an ordinary sine wave oscillator. The grid resistor has high resistance and the grid capacitor is of small value. The product of the values of the grid resistor and the grid capacitor (the time constant, *RC*) is large compared to the time interval of one complete cycle of the tuned circuit.



ARMSTRONG OSCILLATOR

BLOCKING OSCILLATOR

Fig. 2 Comparison of oscillator schematics

The assumption is made that this arrangement gives an extreme case of intermittent oscillator operation, as in a quenched oscillator, and therefore belongs in the sine wave classification. The description of the operation usually takes the following form.

2. Quiescent Period

During the quiescent period, the grid voltage decays toward cutoff value through the grid resistor. This statement as far as it goes is satisfactory. The quiescent period is a convenient point at which to start the discussion. It will be used later in the precise description of operation to permit comparison.

3. Grid Voltage Reduced

When the grid voltage has dropped off sufficiently to permit amplification, oscillation starts. This idea too is accurate.

Oscillation tends to take place at the resonant frequency of the *L* and *C* in the circuit. This frequency is much higher than the fundamental frequency of the actual output waveform. However, the initial surge is timed according to such a frequency, and the terms "quarter-cycle" and "half-cycle," which follow, refer to these fractions of a cycle at the *L-C* resonant frequency.

4. Quarter Cycle Operation

As soon as the negative grid voltage has fallen below the cutoff value, plate circuit conduction starts. The plate current surge is coupled through the transformer to the grid circuit in such a manner as to help make the grid more positive. The change of the grid voltage in the positive direction is thus accelerated. The transfer of the plate current surge to the grid circuit in the form of a grid voltage surge is accelerated by the following factors:

a. The large *L-C* ratio of the tuned circuit. The higher this ratio the less stored energy there is and the faster the circuit responds. In blocking oscillators, the capacitance is usually limited to the distributed value of the transformer and the tube capacitances.

b. The tight coupling of the transformer windings. This minimizes leakage inductance, which would otherwise be a delaying factor.

c. The turns ratio, which is made large so that the grid a-c voltage is large compared to the plate a-c voltage.

These factors cause the start of plate current to be followed almost immediately by a change of grid voltage, so that the latter is driven into positive values. Thus, in the first quarter cycle the plate current rises to such a high value that the plate voltage almost drops to zero, with the peak of the plate coil a-c voltage almost equal to the plate supply voltage.

This very important point is often obscured by the suggestion that the oscillation is determined by the values of *L* and *C* alone. This suggestion does not go far enough, as we shall see later.

5. Grid Capacitor Charge

The high grid drive charges the grid capacitor to a large d-c voltage. Note that the description of the means by which the capacitor becomes charged implies that an induced voltage appears at the grid winding of the transformer. *This voltage alone would not be great enough* to account for the total charge on the capacitor.

6. Half Cycle

At the end of the half cycle, the instantaneous values of the a-c voltage of the coil is zero, so that the grid capacitor is charged to many times the tube cutoff voltage. This explanation again implies that an induced voltage whose frequency is determined by the tuned circuit appears at the grid winding of the transformer, but this time mentions that it has a duration of a half cycle.

7. Oscillation Stops

Because the Q's of the coils are kept low, sometimes through the use of a damping resistor across the transformer winding, the positive peak of the second cycle is too small to bring the instantaneous grid voltage above cutoff. Therefore, oscillation ceases. Here, the transformer is considered as if it were behaving as part of an oscillating circuit, driving the grid to action.

8. Grid Beyond Cutoff

The oscillator does not start again until the grid capacitor voltage, which now biases the tube grid, has diminished to less than the tube cutoff voltage. This is an elementary description of how the quiescent period is terminated.

9. Negative Pulse

The cycle of operation develops a negative pulse between the plate and cathode while the coil system goes through a half cycle of operation. This is rather loose statement.

10. Frequency Determination

The free running frequency of the oscillator is determined by the tube, the coil system, the grid resistor, and the grid capacitor characteristics. For a given tube and coil system, frequency (the recurrence of a cycle) is determined by the time constant established by the grid resistor and capacitor. This too, is a very loose argument.

11. Synchronization

When desired, the repetition rate may be synchronized with pulses or by a-c voltages superimposed on the normal free running grid voltage. The mechanism is the same as that employed for multivibrators. This process develops short pulses of large magnitude.

The preceding explanation contains enough elements of truth so that it is quite difficult to dissect, yet it does have a measure of value for the reader, since it enables him to compare it with the more precise description that follows.

12. Review Questions

(1) Compare the operation of an Armstrong oscillator with that of a blocking oscillator.

(2) Explain what is meant by quenching. Is quenching action used in an Armstrong oscillator?

(3) Does the *L-C* ratio of the tuned circuit in a blocking oscillator influence the timing? Explain.

(4) During operation, is the voltage induced in the feedback transformer of a blocking oscillator of sufficient magnitude to fully charge the capacitor?

(5) Explain why the point made in question 4 is important in understanding the blocking oscillator action.

(6) What stops oscillation in a blocking oscillator? Explain the process.

(7) Name the factor or factors chiefly responsible for determining the repetition rate of a blocking oscillator. In what ways do these differ from the plate-grid multivibrator?

(8) What is meant by the process of synchronization?

(9) Explain briefly what features a blocking oscillator possesses that enable synchronizing pulses to keep it in step.

(10) What types of pulse are most suitable for synchronizing blocking oscillators?

Chapter 3

DETAILED DESCRIPTION OF OPERATION

The operation of the blocking oscillator is so complex that exact formulas for component design, especially for units using little power, are not available. Instead, the oscillator circuit is usually assembled using cut-and-try methods until the desired waveform is obtained to satisfy the specific application. This makes the detailed description heavily qualitative, but it does give a very complete story of the sequence of events.

The circuit arrangement shown in Fig. 3 is used to picture the steps of explanation. Later, as more information appears, required controls will be added.

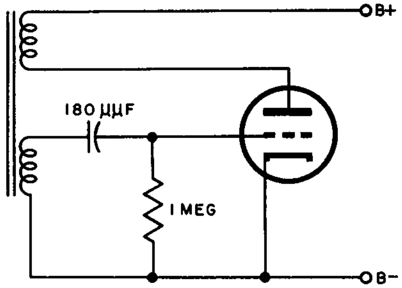
13. Quiescent Interval

This interval is convenient to use as a starting point, not only because it was used in the popular description, but because there is a feeling that less is happening at this time. It does represent the major portion of the repeated waveform as blocking oscillators are usually designed, and it is the interval between the conduction periods, but it is neither a static interval nor a truly quiescent one. In fact, several important things do occur, but these are more easily described at the termination of the conduction period. For reasons that will then be clear, it is best to start with the latter part of the non-conducting interval.

The grid capacitor still has a considerable amount of power stored in it. The source of this power will be discussed later.

The grid capacitor voltage acts in the series circuit consisting of the transformer winding and the grid resistor. This is shown in Fig. 4.

Fig. 3 Blocking oscillator.



The resistance of the grid resistor is many times greater than the resistance of the grid winding of the transformer. Thus most of the capacitor voltage appears across it.

The voltage across the grid resistor appears as a bias voltage between the grid and cathode of the tube. If the tube were to conduct even slightly at this time, it would act as a shunt across the grid resistor and reduce its effective value. This, of course, would cut down the discharge time.

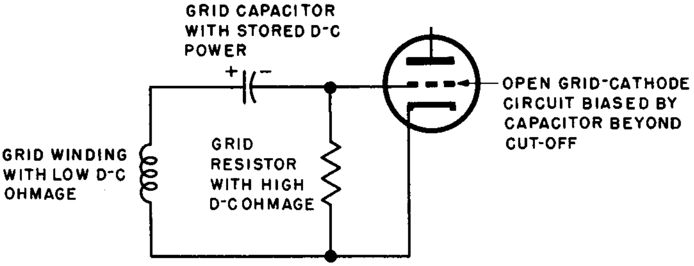


Fig. 4 Series grid circuit.

The bias voltage developed across the grid resistor holds the grid negative. Its action is diagrammed in Fig. 5, showing the relationship between the I_p-E_g and I_p-E_p curves.

In Fig. 5, the relationships of the grid and plate voltages against time may be clearly seen. For example, starting at the bottom left corner of Fig. 5, at t_1, it is seen that the grid-cathode voltage is considerably more negative than the cutoff voltage of the tube. No plate current (I_p) flows, and therefore the plate voltage is equal to the supply voltage. At times t_2, t_3, and t_4 the grid voltage

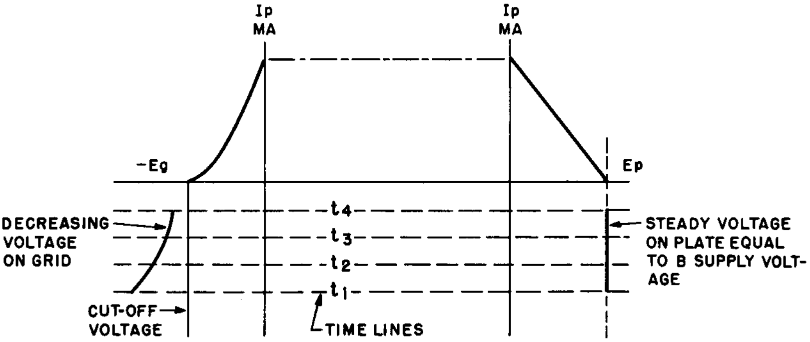


Fig. 5 Grid bias voltage.

decreases and approaches the cutoff potential of the tube, but does not cross it. For this reason the plate voltage remains equal to the supply voltage during this time.

The rate at which the grid voltage approaches the tube cutoff voltage is determined by the time constant of the grid circuit. In computing the time constant, both the real capacitance and the full, total resistance of the grid circuit must be considered. The real capacitance consists of the grid-cathode interelectrode capacitance, the capacitance due to the wiring, and the transformer inter- and intra-winding capacitance in a complex relationship to the grid capacitor proper. However, in our review of this circuit, the problem can be simplified without introducing excessive error by considering the total capacitances as being represented by the grid capacitor and the total resistance by the grid resistor. These component values in a conventional blocking oscillator are selected to have a time constant large enough to make the discharge time great compared to the length of the rest of the oscillator's output cycle.

Throughout the period shown in Fig. 5, the grid voltage remains more negative than cutoff. The tube does not conduct and the plate-cathode circuit resistance remains very high. This means that there is no current flow in the plate winding of the transformer. With zero plate current, the d-c voltage drop across the plate winding is zero, and the full supply voltage appears at the plate of the tube. This is shown in Fig. 6.

Although the conditions of Fig. 5 do approximate the facts, the entire circuit of Fig. 3 should be kept in mind. The grid capacitor voltage decays exponentially. This was shown in the curve of Fig. 5 for the grid voltage from t_1 to t_4. Actually, the power is being dissipated in the grid resistor so that there must be a flow of current. It is small, but it does flow, and it is changing in magnitude. The flow of grid current through the grid winding of the transformer also decreases and therefore establishes an a-c voltage across its terminals. The low rate of change of this current, and its small magnitude, cause it to develop a voltage in the transformer windings having a low frequency and small amplitude. The transformer couples the grid current change to the plate, causing it to appear as a varying potential. This coupled voltage adds to that of the supply. The voltage is, of course quite tiny, both because of the low frequency (gradual change) involved and the small current flow. In many cases it may be neglected.

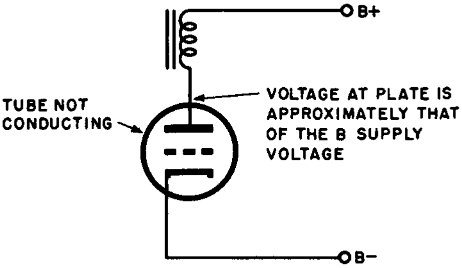


Fig. 6 Plate circuit during non-conducting period.

Although this voltage may appear inconsequential, it does add to the effective plate voltage, thus changing the dynamic characteristics of the tube. This causes the tube to conduct a little earlier than it would otherwise and represents an almost uncontrollable design variable. In addition, this voltage brings about another significant condition; the transformer, having been heavily magnetized previously may still have an appreciable residual magnetism in its core. The current flowing through the grid winding of the coil tends to diminish the residual flux. This decrement in the field is not uniform, and therefore further contributes to the lack of precision in blocking oscillator timing performance.

14. Conduction Due to Grid Bias

As the biasing voltage diminishes (becomes less negative) to the voltage that barely permits conduction, plate current flows. This is shown in Fig. 7, where the plate current flow due to the grid resistor current being transferred to the plate circuit causes the plate voltage to be slightly larger than the supply voltage. The amount of increase shown in the figure is exaggerated for clarity.

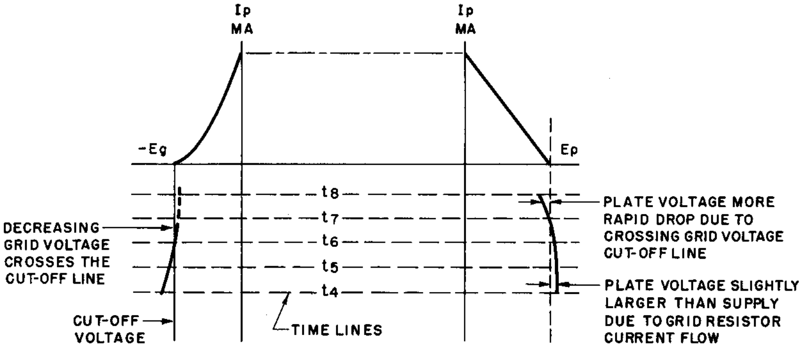


Fig. 7 Conduction due to grid bias.

Then as the grid voltage meets the cutoff voltage line, the plate voltage drops more rapidly, but still rather slowly because the slope of the I_p-E_g curve is very shallow at this point. To obtain a faster decline of the plate voltage as the grid voltage crosses the cutoff voltage line, (i.e., a plate voltage curve with a starting corner that approaches a right angle) other factors must enter into the shaping process. The sharpness of the plate voltage drop is referred to as plate voltage drop-time.

The slow start due to the gentle slope of the beginning of the I_p-E_g curve is also an indication of the low transconductance (G_m) characteristic of the tube at this point. (G_m is a ratio of the change in the plate current produced by a specific variation in grid voltage.) Here, the plate current change per grid voltage change is small compared to the same ratio in other parts of the E_g-I_p curve.

To obtain a square plate voltage "corner," compensation must be made for the low transconductance at the beginning of conduction.

15. Conduction Due to Regeneration

As soon as conduction begins, some plate current flows, as was shown in Fig. 7. This means that the resistance of the plate circuit of the tube itself has decreased, for obviously no current can flow through the circuit of Fig. 6 when the tube is cut off. As the current flows, the B-supply voltage that had appeared across the tube before conduction now distributes itself across the transformer and the plate-cathode circuit of the tube. As the current flow increases, more of the supply voltage appears across the transformer winding and the voltage across the plate-cathode circuit decreases. This current produces a magnetic flux in the core of the transformer.

Blocking oscillator transformers have two distinguishing design characteristics. Their cores are fabricated of highly permeable material, a factor that makes for high energy storage, and the primary and secondary windings are wound on the core at the same time. This winding arrangement is called *bifilar* and is shown in Fig. 8. With this arrangement, nearly all of the magnetic flux lines caused by the current through the plate winding cut the wire of the grid winding. With such tight coupling there is little flux leakage and substantially smaller power loss.

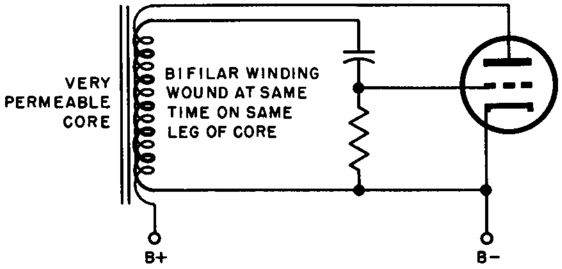


Fig. 8 Bifilar winding.

Thus, when the grid voltage crosses the cutoff line, feedback voltage produces the effect of greater starting G_m than without feedback. This is illustrated in Fig. 9 and explained as follows:

Plate current increases under control of the grid voltage, until plate current change generates grid circuit voltage through the transformer. This grid voltage, being positive, further increases the plate current flow until losses are all overcome and regeneration commences. Regeneration causes the grid voltage to rise more rapidly. Of course, the circuit is arranged for positive feedback by properly orienting the plate winding in relation to the grid winding.

The regenerative process involves *power* that is fed back to compensate for normal transformer losses due to such things as hysteresis, eddy currents, copper losses, radiation, and mechanical movement of loose cores; all of which dissipate power wastefully as heat. The demands of these power losses must be satisfied by feedback before regeneration can take place.

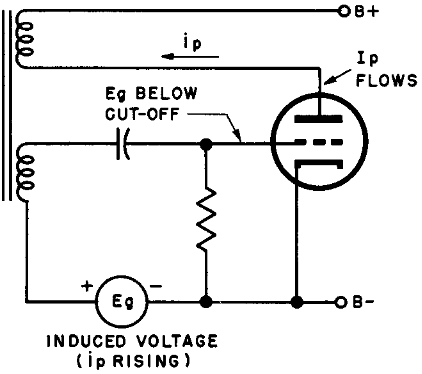


Fig. 9 Regeneration effects.

Another action that is important, is capacitor "override." As shown in Fig. 10, the capacitor voltage has been decreasing toward cutoff, and has just crossed the cutoff line. That is, the grid negative potential is now a little lower than the cutoff voltage and permits tube conduction. The true grid voltage of the tube is the voltage induced from the plate circuit less the capacitor voltage remaining from the preceding quiescent period and any resistance-current drop in the transformer winding.

16. Conduction Due to Circuit Elements

The blocking oscillator transformer is subject to certain other rigorous requirements. One of the most important is frequency response. A sine wave oscillator does not demand wide bandpass characteristics of its transfer components, but a blocking oscillator having square cornered waveforms in its output is much more critical in this respect, because these square cornered waveforms are composed of a wide band of frequencies. It might be pointed out that the duration of a pulse is measured by the low frequencies in the signal, while the fall and rise time of the pulse is due to its high frequency components.

In a transformer with a high-permeability core, fewer turns are required to develop the necessary inductive reactance. Fewer turns result in less distributed capacitance. The lower capacitance makes the natural resonant frequency of the coils higher. This is an important item in the shaping of the fall and rise time of the pulse. It should be remembered that the natural period of the tuned circuit does not control oscillation repetition rate in the blocking oscillator, but it does affect the *rise* and *fall* time and the overshoot, as we will see. The low inductive leakage path in the coils of the transformer, resulting from the use of bifilar windings, permits a low impedance feedback or transfer path from the plate to the grid circuits. This further decreases the fall and rise times of the pulse and tends to keep the time lag between the signals in the plate and grid circuits small.

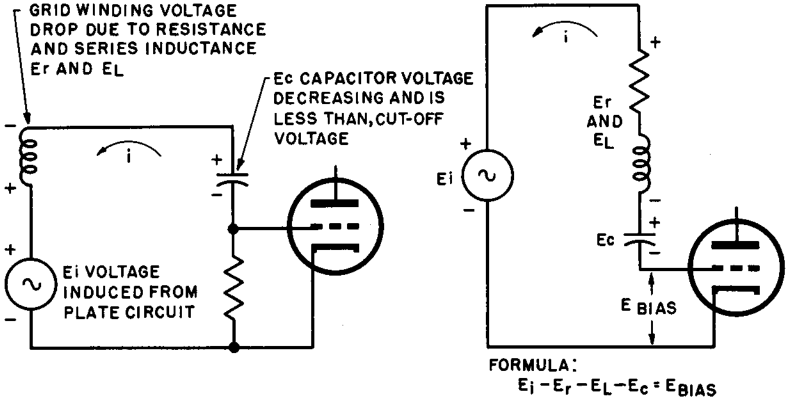


Fig. 10 Over riding bias.

To keep the *Q* of the transformer very low, a loading resistor is sometimes connected between the terminals of the plate winding of the transformer. It may in some cases be placed across the grid winding. Critical damping of the transformer is obtained when the loading resistance is half the square root of the *L*-*C* ratio, where *L* is the inductance of the winding across which the resistor is to be placed and *C* is the distributed capacitance of the winding. To provide heavier damping, the square root may be divided by four instead of two, to obtain the load resistance value. For the usual triode, the damping resistor should be one third of the plate resistance of the tube, and the mu of the tube (amplification factor) should be greater than 5.5 times the turns ratio of the transformer. This means that the common one-to-one transformer turns ratio may be used with any standard triode having a mu of 5.5 or better.

Tubes with oxide coated cathodes are normally used to produce continuous but limited emission and are satisfactory for the large current, short conduction periods of blocking oscillators. Judgment should be exercised in determining the conduction period because, if it is too long, the average power dissipation rating of the tube will be exceeded. Reference is sometimes made to the ratio of pulse duration to pulse repetition time as a duty cycle. The duty cycle current may be several hundred times larger than the average value of current because it has such short duration. With medium sized tubes, like the 829, it is possible to develop kilovolt potentials and power in the kilowatt range.

Mention has been made of the effect of the grid capacitor size on the time of discharge during the quiescent period. The size of the capacitor also affects the length of the conduction pulse. While the transformer is transferring power from the plate circuit to the grid circuit, the impedance of the grid circuit is a function of the size of this capacitor. If its capacitance is small (reactance high) the low frequency components of the pulse cannot enter the circuit and the pulse is short in duration and is misshaped. Whether the capacitor is small or large, the fall and rise time is not materially affected, but the duration of the pulse and its waveform definitely are.

17. Combined Conduction Effects

A brief review of conduction effects is desirable at this point to clarify the interrelationships betwen the individual steps.

The voltage on the grid prior to conduction is the outcome of the stored energy on the grid capacitor. This stored energy is dissipated in the grid resistor, and the grid voltage decreases. At the instant the voltage across the grid resistor falls to the cutoff voltage of the tube, the latter tends to begin conducting. The initial plate current due to the capacitor is quite small, because the transconductance of the tube is not as great at the start of conduction. The slope of the grid voltage curve continues very nearly

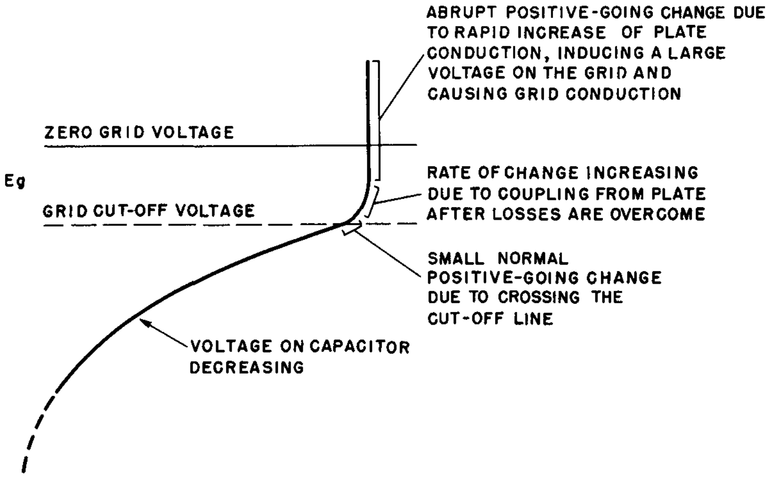


Fig. 11 Grid voltages.

the same as the slope that existed before the cutoff line was crossed. This is shown in Fig. 11. Shortly after conduction starts, and while the transformer losses are being supplied, a small voltage change in the positive direction is transferred to the grid through the transformer by the changing plate current.

The phase of the feed back voltage in this case is such as to speed the decrease of the already falling negative grid potential, causing it to become positive more rapidly. As the G_m grows gradually, the transfer from plate to grid becomes proportionally more significant, resulting in an additional sudden increase of the grid voltage.

The resulting plate voltage waveform is shown in Fig. 12. The plate-cathode potential is initially close to the value of the supply voltage. As the grid voltage crosses the cutoff potential of the tube the plate voltage starts to drop. The G_m contributes still further to the rapidly steepening slope of the plate diminution curve. Now grid current begins to flow. The flow of grid current (I_g) is shown in Fig. 13. This flow is large, as indicated on the figure.

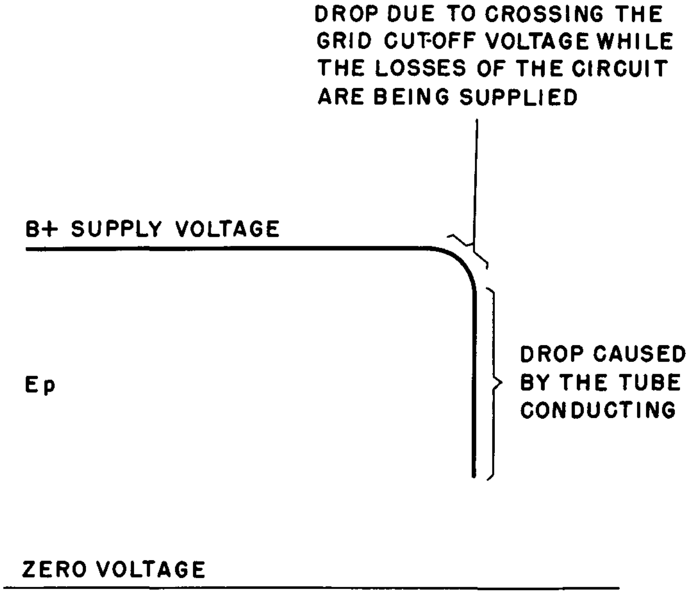
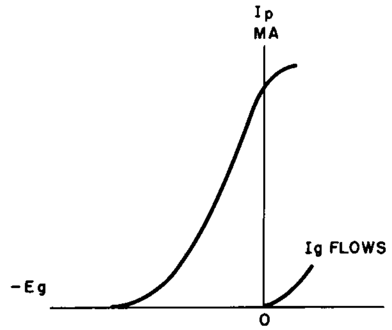


Fig. 12 Plate voltage variation during, and just following, plate cutoff period.

The internal resistance of the tube, which has been very high, now decreases. The voltage from the discharged grid capacitor may be neglected, though it is not small. The voltage due to regeneration through the transformer at this time is positive, as shown in Fig. 14, and the capacitor-grid-cathode circuit becomes a heavy load on the transformer. This causes the capacitor to charge. The charging process continues. In the *L-C* sine wave oscillator, the capacitor normally takes control and stops the tube from conducting. Here, the large voltage that transferred from the plate circuit causes the grid to become very conductive and lose control of the plate current. The design of the transformer (high storage ability) makes the power available in the plate circuit large.

Consider the condition that now exists. The grid is heavily positive while the capacitor charges to a large voltage. The plate circuit has become very conductive. The plate voltage is small because the tube is conducting. The power stored in the transformer is being dissipated in the grid circuit. This is the crux of the blocking oscillator's operation. In no other oscillator does all of the energy of the plate "spill" into the grid circuit; in no other oscillator is the conduction period free of the *L-C* resonant characteristics of the coils and their distributed capacitance. Of course, this "spilling" action must come to an end. When the power stored in the transformer is diminished below the value required by the grid circuit, the "spilling" stops. At this time, the gain of the tube also decreases somewhat because the plate voltage has dropped so low. This is shown in Fig. 15.

Fig. 13 Start of grid current flow.



THE CAPACITOR VOLTAGE HOLDING THE GRID NEGATIVE IS OVERRIDDEN BY THE TRANSFERRED VOLTAGE MAKING THE SUM OF THE VOLTAGES ZERO AND THEN BECOMING POSITIVE - THEN GRID CURRENT FLOWS.

Throughout the interval during which power is being fed back to the grid circuit, a reasonably steady condition exists. During this period the positive portion of the grid signal is developed. The heavily loaded secondary shown in Fig. 15 causes the current through the transformer to change linearly, and the grid voltage remains steady at one level. This is diagrammed in Fig. 16.

In practical circuits, the pulse may be kept active by means of energy from an external trigger. This then supplies the power necessary to maintain the steady state.

18. Summary

The conduction phase may be summarized as follows:

1. The grid voltage causes the tube to become conductive.
2. The plate voltage diminishes to a small value.

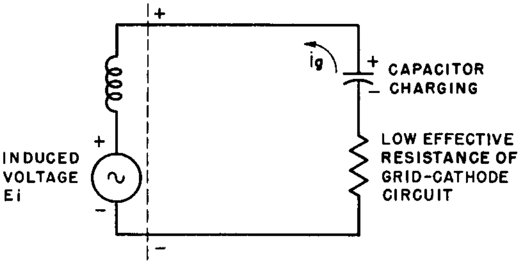


Fig. 14 Transformer grid circuit load.

3. While the tube conducts, the power stored in the transformer, as the conduction is started, is released.
4. This power is "spilled" into the grid circuit.
5. The power is dissipated in the losses of the transformer, the tube's grid-cathode circuit, and the external loads.
6. When the power is fully dissipated, conduction terminates.

19. Oscillations That Occur During the Conducting Period

When the tube is forced into conduction by the regeneration effect, the plate circuit consists of a source of power having measureable reactance. The reactance is composed of the small leakage inductance of the transformer and the stray capacitance of the transformer and other components, including the plate-cathode impedance of the tube. In circuits where there is little resistance to dissipate or "damp-out" the shock of abrupt conduction for the reactive elements, the plate voltage generally changes at the rate of the resonant frequency of these elements. This is known as shock-excitation or ringing, and is shown in Fig. 17 superimposed on the plate voltage curve.

This damped wave due to ringing may be minimized by loading the circuit with resistance. A standard loading procedure consists of connecting a resistance across the plate winding of the transformer. In some cases, a resistor shunts the grid winding to damp out the tendency of the circuit to ring. In other arrangements, the resistive components of the circuit are made large enough to keep the reactive components from setting up a damped wave. In still others, the output circuit is used to load down the reactive components.

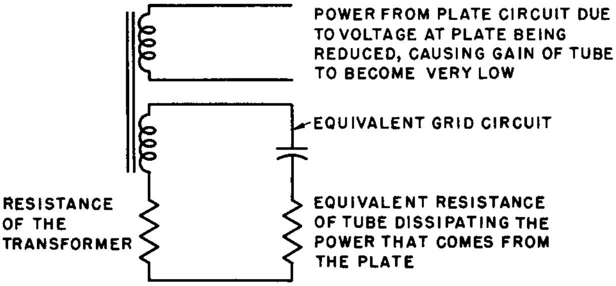


Fig. 15 "Spilling" power.

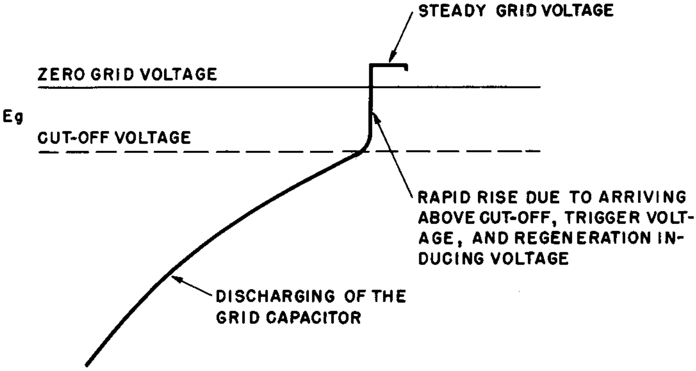


Fig. 16 Grid voltage variation from the beginning of the plate cutoff period through the conduction period.

20. Determining Conduction Duration

Conduction starts when the grid voltage becomes smaller than the cutoff voltage of the tube. With the feedback voltage transferred through a transformer with little leakage inductance, the grid is quickly swept into its positive region and conductance in the plate and grid circuits is very great. The plate voltage drops to a very small value. Under these unusual circumstances, the transconductance of the tube becomes smaller than normal. Actually, the grid loses control of the plate current flow while power that had been stored in the transformer is transferred to the grid circuit. During this time the capacitor becomes very heavily charged. The voltage to which it is charged may be as great as the plate supply voltage or very near that amount.

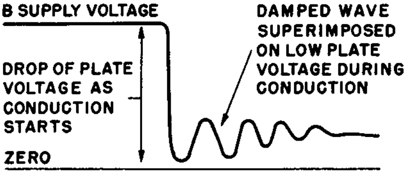


Fig. 17 Damped wave on conduction pulse

When the grid circuit can no longer be fed power by the spent source in the transformer, it again gains control of the plate current flow, and conduction ceases in both the plate and grid circuits. The grid voltage then controls.

The conduction period is lengthened by increasing the size of the grid capacitor. This effect is due to the larger "reservoir" feature of the capacitor or its ability to hold a larger charge. Also, as discussed earlier, the larger the capacitor, the lower the load impedance of the grid circuit, a condition that lengthens the conduction period because the lower frequencies can be transferred successfully.

The conduction period is also increased by the ability of the transformer to store energy. This is the function of its self inductance, the amount and type of the core material, and the damping introduced by the resistance of the transformer. The core material must, of course, be able to store all of the energy needed to continue the conduction period for as long as needed for the particular application, or saturation of the core will interfere with operation and terminate the period during which the power is being transferred from the plate circuit to the grid circuit.

Another agent that controls the length of the conduction interval is the tube itself. It supplies the stream of electrons needed to establish the transfer path. For example, if the cathode of the tube cannot emit enough electrons to provide the grid and plate streams, the interval of conduction is diminished in either duration or size or both. This is true when a tube of high mu is used and when the impedances of the grid and plate paths are too high to permit the flow of enough electrons.

The conduction period may be terminated by means of a trigger pulse. Such a pulse may be introduced in a number of ways, which will be discussed later. Regardless of the method used, however, its action is basically that of allowing the grid again to assume control over conduction.

The length of the conduction period is determined by the size of the capacitor, the construction and materials used in the transformer, the various pertinent tube parameters, and the means used to control the duration of the pulse.

It should be added that the fall and rise times of the pulse are controlled by the ability of the transformer to transfer the high frequency components (required to reproduce a sudden change) from the plate to the grid circuits. These are in turn governed by the design of the circuits in and about the transformer (the capacitance of the transformer windings; the core material; the inductance, both self and mutual, of the coils; the reactive elements of the wiring, the tube, and other elements that form a part of the circuit of the transformer and cause it to resonate at some frequency). These resonant circuits limit the frequency of the transmitted band and the response characteristics of the transformer, hence the rise and fall times of the conduction pulse.

It may be shown that the conduction pulse for one blocking oscillator appears like that shown in Fig. 18.

In this figure the stray capacitance is shown as C_g, and the damping resistor is also shown. These are not important at this time for this discussion. At point 1 in Fig. 18, conduction has just commenced, since grid voltage has just passed the cutoff voltage. The rounded portion of the curve is controlled by the low mu of the tube as conduction starts. This was not emphasized in Fig. 18 in order that the entire curve might be shown. Point 2 shows the steepness of the conduction pulse and the fall time, the slope of which is determined by the frequency response of the transformer and the size of the grid components. At point 3 the grid voltage has become greater than the plate voltage while the transformer is "spilling" its power into the grid circuit. This governs the duration of the pulse, which, of course, is greatly dependent upon the size of the grid capacitor. Point 4 shows the rise time of the pulse, which is again dependent upon the pulse transfer from the plate to the grid. The shape of the curve at point 5 is due to the dissipation of power in the plate circuit, an effect to be discussed later.

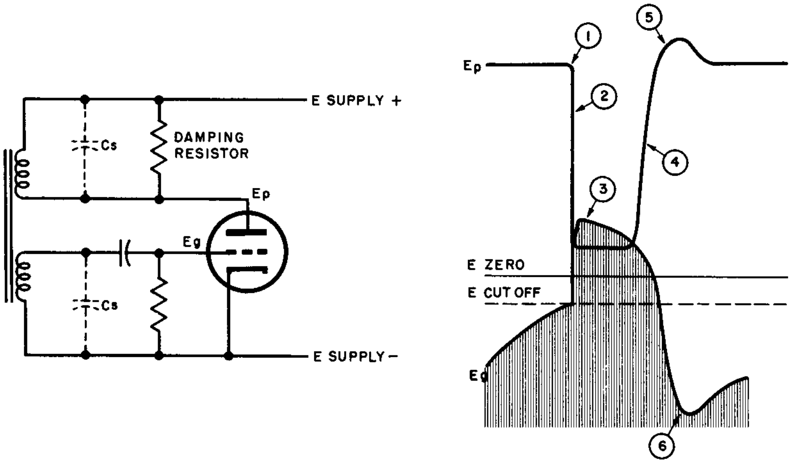


Fig. 18 Plate and grid voltages plotted together.

Point 6 locates the end of the charge period of the grid circuit and the beginning of the discharge of the grid capacitor, thus ending the positive pulse period.

21. Termination of Conduction

In Fig. 18, at point 5, it was shown that the end of the pulse is marked by the completion of transfer of energy from the plate to the grid circuit. Of course, all of the energy cannot be so transferred, because the impedance of the grid circuit rejects the power that is below the threshold of absorption. This leaves some power in the plate circuit unconsumed. Some of it may be dissipated in the load, some in a damping or ringing resistor. However, some power remains and must be dissipated in the plate circuit. This residual energy cannot reach the grid circuit because the grid circuit has taken on a high impedance characteristic, hence it appears in the winding of the transformer as a reserve potential and is illustrated in Fig. 18 as an increase in the plate voltage. This surge is often referred to as an overshoot and represents the increased voltage at the plate of the tube due to the release of residual transformer power. The extent to which the plate voltage rises can be controlled by the design of the transformer and the size of the damping resistor, as well as by controlling the distributed capacitance of the circuit.

The time of termination of the pulse depends upon the low frequency response of the circuit bringing the power pulse from the plate to the grid circuit. It has already been shown that the capacitor plays an important part in this arrangement. If it is omitted, as it is in some circuit arrangements, the low frequency response of the transformer limits the duration of the pulse. Where the transformer is constructed with a "butted" core, providing a small air gap between the sections of the core, the duration of the pulse is affected because two important features of the transformer have been altered. These are the amount of inductance that a specified amount of core material may produce, and the degree of demagnetization that may be engendered. Saturation of the core makes the demagnetization of the core important because a second pulse cannot be formed until the first pulse is "wiped off" the core. This causes the incremented plate voltage at the end of the pulse to be very large.

The greater the effective inductance of the transformer, the better is its low frequency response and the greater is the length of the pulse that can be developed. In transformers without a core gap, the high current at the peak of the conduction pulse may saturate the core; this causes the effective inductance to decrease and pulse duration to become less. Provision of an air gap in the core reduces saturation and would be expected to increase pulse length.[1]

In any event, the further the transformer is driven into saturation, the lower is its effective inductance and the shorter is the maximum pulse duration.

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[1] This is not always true, but the reasons have never been completely explained. See Chance, Hughes, MacNichol, Sayre, and Williams, *Waveforms* (New York: McGraw-Hill Book Co., Inc., 1949), p. 212.

One method of minimizing the effects of saturation of the transformer core is to bias the core magnetically in a direction opposite to the magnetism created by the plate current peak. This can be done by the methods illustrated in Fig. 19. At *A* shunt feed is employed. Direct current is fed to the plate through a resistor or choke coil and the transformer is isolated from the tube by capacitors whose reactance is relatively low at the fundamental frequency of the oscillator's output waveform. At *B* a separate winding is connected to a source of direct current. The direction of the current and winding sense are such that a "bucking" magnetic field is set up in the transformer.

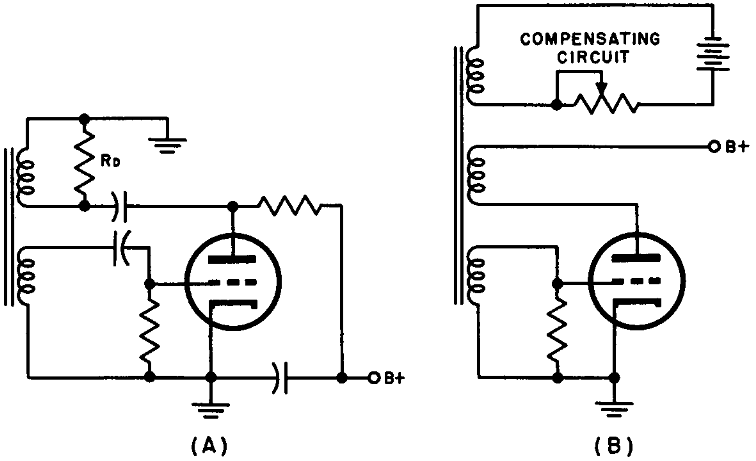


Fig. 19 Two methods of extending the minimum oscillator frequency magnetically: (A), by keeping direct current out of the transformer (shunt feed) and (B), by direct current in additional winding to compensate for saturation tendency in transformer during current peaks of operation.

Also, such methods as lowering the plate voltage to reduce the effective mu of the tube may also be used. This makes it possible to slow down the rise and fall times and reduce the amount of power that is available to the circuit.

An additional effect of increased plate voltage at the end of the pulse is the creation of a degenerating voltage in the grid circuit, which hastens the end of the pulse and makes the fall time shorter.

As previously mentioned, the pulse termination may also be controlled by triggering voltages that are introduced in the circuit in a number of ways, as we shall see later.

22. Shock Excited Circuits

At the completion of the conduction pulse cycle, there may be some oscillations present on the increased plate voltage curve, as there was at the beginning of the conduction period. These are due to the ringing of the plate winding of the transformer and the capacitance that tunes it. Usually, these oscillations dampen out quickly.

Seldom are the oscillations due to the mutual impedance, because the grid circuit at this time has virtually infinite impedance. This prevents ringing in the mutual inductance, but the grid winding inductance may tune with its distributed capacitance to produce damped oscillatory waveforms.

It is possible to tune one of the windings by placing a properly selected capacitor across it. In this way the augmented plate voltage at the end of the pulse may be made great enough to start a second interval of conduction. These oscillatory periods are terminated by self quenching oscillator action rather than blocking oscillator action.

Waveforms of parasitic oscillations are shown in Fig. 20. These modify the curves of Fig. 18 to show how the oscillations appear on the basic grid and plate voltage curves. These curves are (as were the prior waveforms) idealized, but they do indicate what can happen to both the start and end of the conductance pulse when the design permits oscillations to occur in the plate and grid circuits.

23. Start of Quiescent Interval

When the capacitor has charged and has taken over control of the circuit, residual energy in the plate and grid circuits must be dissipated. This energy conversion occurs in the tuned circuits after the oscillations of Fig. 19 have stopped.

These do not often constitute a major problem, unless the original design ignores the difficulties to which they may lead. Energy in the grid circuit can give rise to an over-riding effect in which the energy stored in the grid capacitor may start a second cycle, a condition that tends to stop blocking oscillator operation.

This is more likely to occur in circuits where the transformer core is fabricated of continuous magnetic material (for example, wire or rings of material without air gaps). Construction of this nature encourages the growth of high intensity magnetic fields, which must collapse at the inception of the quiescent period.

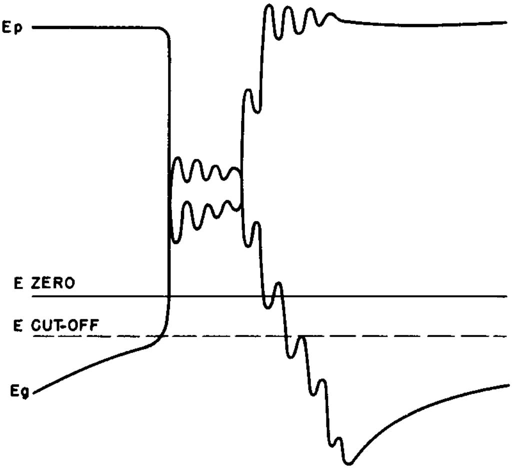


Fig. 20 Parasitic oscillations on normal waveforms.

24. Review Questions

(1) In deriving the parameters of blocking oscillator circuits, why are exact formulae not utilized in most cases?
(2) Exactly what is meant by the quiescent interval in the period of a blocking oscillator?
(3) Draw a schematic diagram of a blocking oscillator and indicate with arrows the path through which the capacitor discharges.
(4) Explain why the time for discharging this capacitor may be quite long.
(5) Why is the plate voltage the same as the supply voltage during the discharge period of the capacitor?
(6) What causes the slope of the I_p-E_g curve to be shallow at the moment the grid starts to conduct?
(7) Explain how regeneration aids in charging the capacitor.
(8) Describe the features that a good blocking oscillator feedback transformer must possess.
(9) What is a bifilar winding and why is it used?

(10) List the normal transformer losses that must be compensated for by the power fed to the system from the power supply.

(11) How large should the damping resistor be? Explain.

(12) Draw a diagram showing the waveforms found in the grid and plate circuits of an operating blocking oscillator.

(13) Would you say that the plate resistance of the tube in a blocking oscillator is large or small? Explain.

(14) What is meant by "spilling"?

(15) Outline the six steps in the conduction phase of a blocking oscillator.

(16) How are oscillations due to the shock of abrupt conduction stopped?

(17) What are parasitic oscillations? How do they come about?

Chapter 4

APPLICATIONS

25. Circuit Classifications

Blocking oscillators may be classified in a number of ways. A popular basis for classification is one that depends upon the manner in which recycling is accomplished. For example, in some types fixed bias of cutoff or greater value is applied to the grid. Such a circuit may be made to recycle from the quiescent state by adding a large positive pulse (from an external source), which cancels the cutoff grid potential.

If such a pulse is necessary to overcome the fixed bias that is initially present, the circuit is called a *monostable* blocking oscillator. If the pulse is not needed to re-establish operation of the blocking oscillator (that is, if the grid voltage is allowed to become low enough or positive enough to cause conduction) the circuit is called an *astable* blocking oscillator. An astable oscillator may be recycled earlier than its free running time by introducing a synchronous pulse train of proper polarity and waveform into the grid circuit. Such a circuit is referred to as a *synchronized astable* blocking oscillator.

26. Blocking Oscillator Functions

Blocking oscillators serve many purposes. Many are used in television sets, where they maintain operation on a free running basis, but synchronized either periodically by pulses, or continuously by application of controlled d-c bias.

One of the important uses of a blocking oscillator is to establish a time base for the operation of other circuits. It is sometimes designed to measure the size of the synchronizing pulse. When the incoming synchronizing pulse is low in amplitude, the oscillator remains cut off. The oscillator may be arranged to fire as soon as the sync pulse attains a specified dimension. This application is likely to cause the output to vary with respect to time, and if used in television or smaller presentations of the signal wave, it will make the repetitive fields vary in position. This effect is usually referred to as "jitter" for it makes the presentation appear to jump irregularly and irritatingly.

Power dissipation is not a major concern in circuits used in such applications as receivers. Nevertheless, in *all* applications the blocking oscillator is relatively economical because the power is taken from the supply only when the current pulse is being developed. Thus it is an inexpensive circuit for generating high power pulses even when recurrent waveforms must have identical shape.

Blocking oscillators make superlative switching devices. One switching application is pictured in Fig. 21. It is used in a current television design. The circuit and waveforms are highly idealized. They show that the synchronizing pulse is needed to establish the exact timing of the positive grid pulse, E_1. The positive grid pulse is used to discharge capacitor C partially. This capacitor recharges during the quiescent period. The blocking oscillator acts as a switch, turning the second tube on and off to effect the discharge and charge of capacitor C.

In considering the applications of blocking oscillators, frequency dividers and step counters should not be omitted even though there is a tendency toward increased utilization of multivibrators rather than blocking oscillators for this purpose.

27. Design Arrangements

Figure 22 compares the astable and monostable blocking oscillators. The astable type runs freely at a frequency determined by the circuit constants. The monostable circuit does not recycle until the grid capacitor attains the voltage of the grid bias battery, minus cutoff bias.

In Fig. 23 a monostable blocking oscillator is shown with the plate circuit arranged to keep the direct plate current from flowing in the transformer winding. It is the same as the circuit of Fig. 19, except that a choke is used in the plate circuit, instead of a resistor. This arrangement increases the pulse width because the effective value of the permeability of the core is not reduced by the biasing effect of d-c flowing through the winding. Here the plate capacitor (C_p) must be kept large enough to pass all of the low frequency components of the desired waveform.

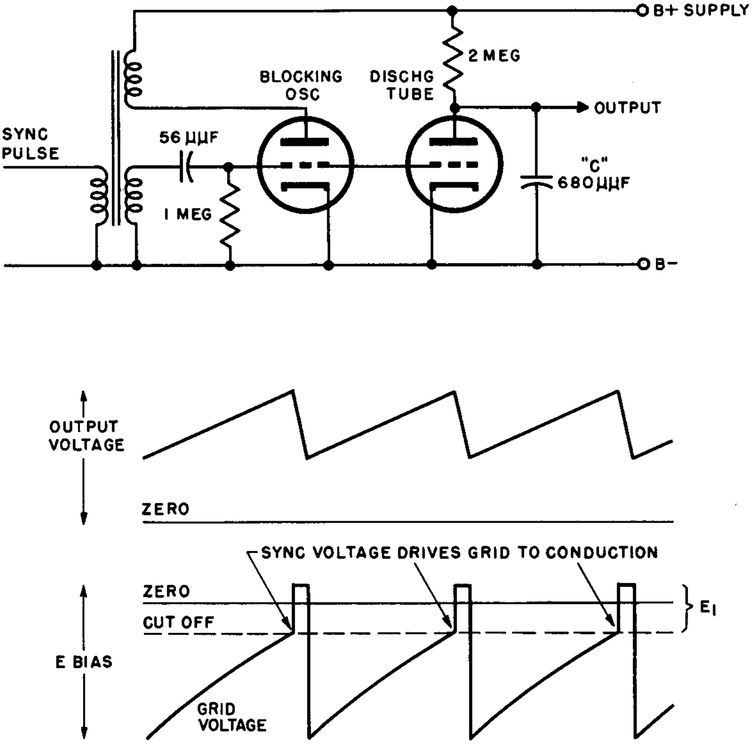


Fig. 21 Switching application.

28. Triggering

Triggering refers to the introduction of a current or voltage pulse that starts or ends the conduction interval. In current forms of starting the interval, the pulse may be introduced into the transformer winding in parallel with the normal plate current circuit, in which case it is called parallel triggering. For a series action, it may be introduced in the grid-cathode circuit. The more common name for triggering is synchronization. It refers to the injection of a timing pulse to establish recycling at the specific instant. These triggering methods are diagrammed in Fig. 24.

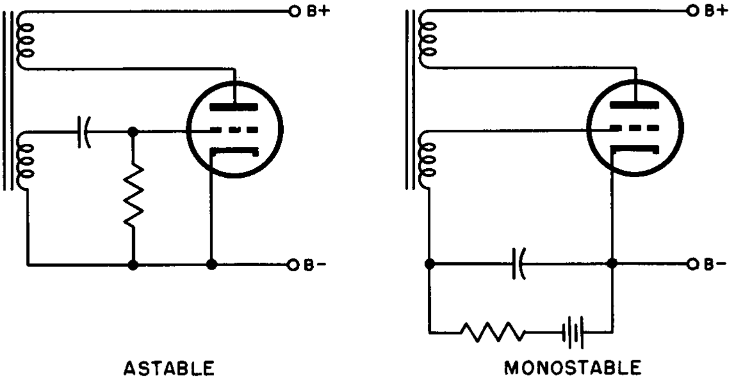
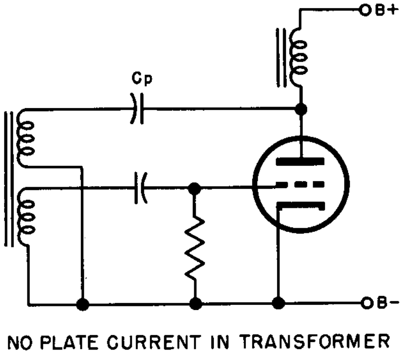
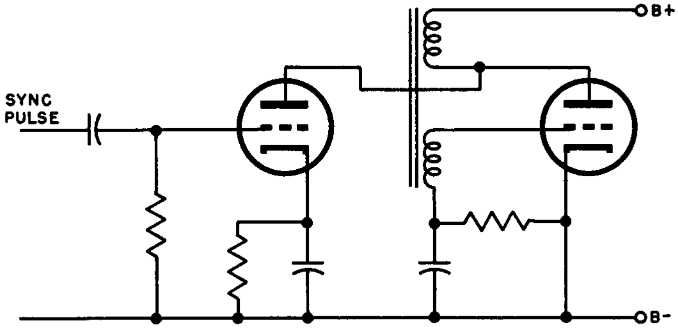


Fig. 22 Comparing blocking oscillators.

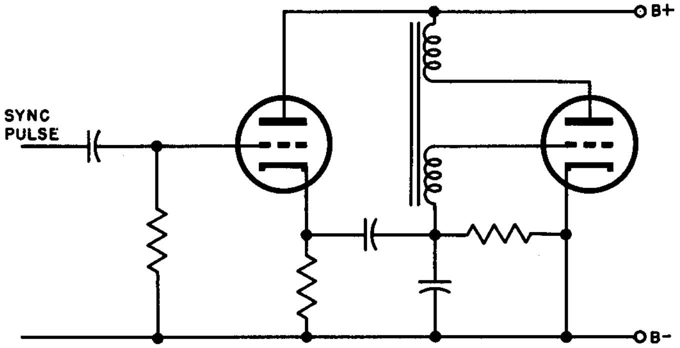
Fig. 23 Monostable blocking oscillators.



In parallel synchronization, the synchronizing pulse is applied through the amplifying tube to produce a current flow through the plate winding of the blocking oscillator transformer. In the series method, a voltage pulse is applied to the grid circuit of the blocking oscillator. In either case, the oscillator is made to recycle.



PARALLEL TRIGGERING



SERIES TRIGGERING

Fig. 24 Synchronizing or triggering methods.

Although it is possible to inject synchronizing energy directly into the controlled tube, the use of an isolating amplifier, as shown in Fig. 24, is to be preferred because it prevents interaction between the controlled stage and the synchronizing source, and because it increases the amplitude of the transmitted pulse.

Series synchronization has the advantage that less power is required. This permits the use of "slow" slope signals. The amplifier increases the slope of the pulse and a steeper front appears at the blocking oscillator grid. This has a marked advantage in that, in shaping the rise time of the pulse, there will be more accurate timing compared to the original synchronizing pulse.

Both the series and parallel methods of synchronization are shown in Fig. 25. The input pulse is rectangular in shape and is

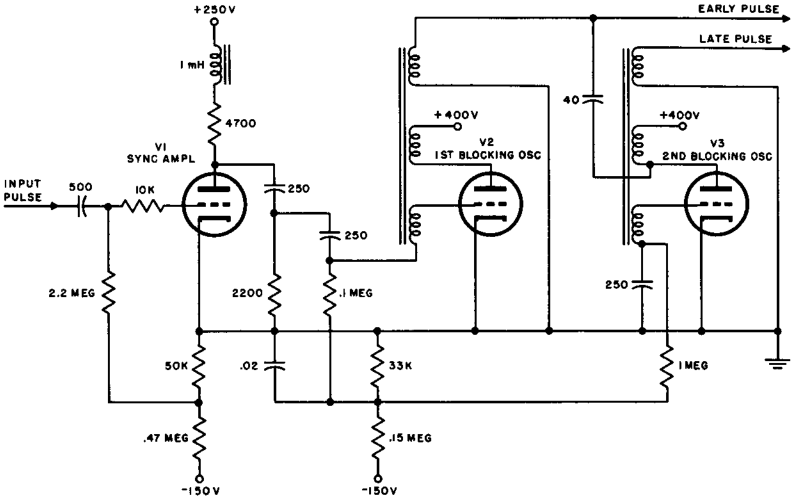


Fig. 25 Airborne radar application.

differentiated in the first stage to produce a sharp positive pip at the end of the pulse. This causes the first blocking oscillator to fire by the series method. It will be observed that the pulse is delivered as a voltage to the grid in series with the grid winding.

The output of the first blocking oscillator is used to obtain an early pulse to drive some later circuit. A small portion of this output is used to synchronize the second blocking oscillator by the parallel method. The $40\text{-}\mu\mu\text{f}$ capacitor in the plate circuit of the last tube causes the pulse to be partly differentiated. The negative pip starts the oscillator operation to produce the "later" pulse. A portion of this pulse is also used to drive the first oscillator into quiescence.

29. Control of Recovery Time

The time required for the blocking oscillator to recover from the voltage that holds it in quiescence may be controlled in a number of ways. Figure 26 illustrates a circuit in which controlling *R-C* elements are placed in the grid and the cathode circuits. These may be arranged to determine the length of the grid cutoff interval independently or in combination.

In this application *R3* and *C2* are the cathode biasing arrangement. *C1* and *R1* are the grid units. Both of these *R-C* time constant combinations must recover before the blocking oscillator will fire.

Other arrangements make use of a nonlinear element in place of or across the resistors to vary the recovery time of the *R-C* combinations.

30. Delay Line Control

One of the outstanding faults of the blocking oscillator is its inaccurate repetition rate. As explained previously, trigger voltages are used to overcome this. However, this means that another circuit is necessary to establish trigger voltages, and this is in itself a handicap.

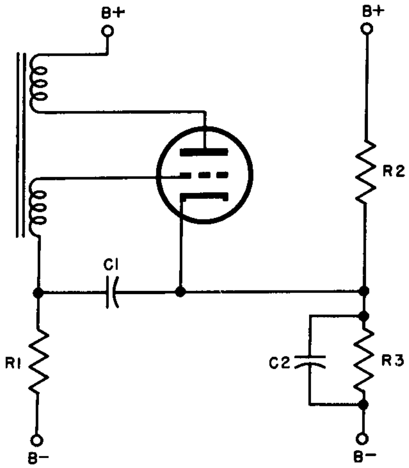


Fig. 26 Control of recovery time by addition of circuit elements *R1, C1, C2, R2, R3,*

Another manner of establishing repetition rates on a stable basis is through the use of a transmission line as a timing arrangment. There are many ways in which this can be done. Some of these will be described.

In principle these all depend upon the time it takes a pulse to be transmitted down a length of line and/or back. Transmission lines are not used to determine repetition rates in television sweep circuits for two important reasons. The first is the long interval involved in sweep circuits. It will be remembered that even the more rapid horizontal sweep has a required time recurrence of

63.5 microseconds, and this is much too long for a transmission line to time. The second reason is that the sweep time must follow the transmitted rate of the broadcasting station. These transmissions are not always accurate time-wise, and therefore a perfectly accurate source established by a transmission line would serve no purpose. Transmission line delay circuits are used in such applications as radar and similar systems where delay is in the order of a microsecond or less. They are also used in color television, an application that will be specifically described.

A two-wire transmission line that introduces a delay even as short as one microsecond would require a line nearly a thousand feet long. This would be difficult to handle and to find space for in most applications. Instead, simulated lines (also known as artificial lines) are used. Artificial lines are assembled from inductors, capacitors, and sometimes resistors, which simulate the distributed constants of a transmission line of the desired delay. By using a number of sections, each corresponding to the constants of a small line section, an artificial line is made to simulate a real transmission line. The inductance is connected in series with the length of line to simulate the inductance in the real line. The capacitors are connected in shunt to simulate the capacitance between the wires of a real line. There are more complex arrangements of the components used to secure certain effects, approaching specialized filters, but the simpler arrangement is sufficient for our first consideration of the principles involved. The usual arrangements are shown in Fig. 27.

The artificial line should consist of small units representing short lengths of the line it is supposed to simulate. The inductances labeled L_a are on the active side of the line. Where lines must be balanced, both the L_a and L_i inductors are needed. Artificial lines are usually made to work in conjunction with amplifiers, and these are usually unbalanced networks. In an unbalanced line the L_i inductors are omitted.

Unbalanced sections of line may be made up in any of a number of ways. In Fig. 28A, the line is composed of "T" sections. Each inductor has one half the inductance of a whole section. Where half-sections are connected together, the half-inductors are combined to form the inductance of the entire section. The capacitors are arranged to represent the full capacity of the whole "T" section.

In Fig. 28B, the line is composed of "π" sections. Here each capacitor represents half the capacitance of a whole section and each inductor has the inductance of a whole section. When half-sections are combined to form a line, the half-capacitors of each joined section combine into the full capacitance of a whole section. Only the end capacitors are half-units.

In Fig. 28C, the line uses "L" sections, and both the capacitors and inductors represent whole section capacitance and inductance.

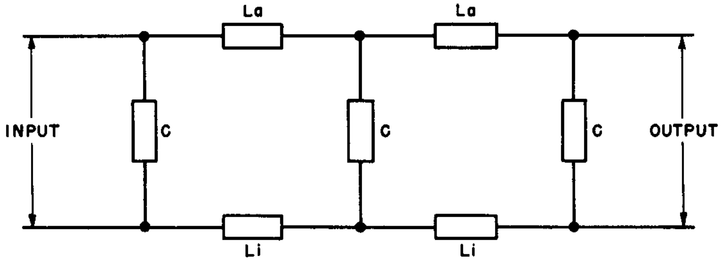
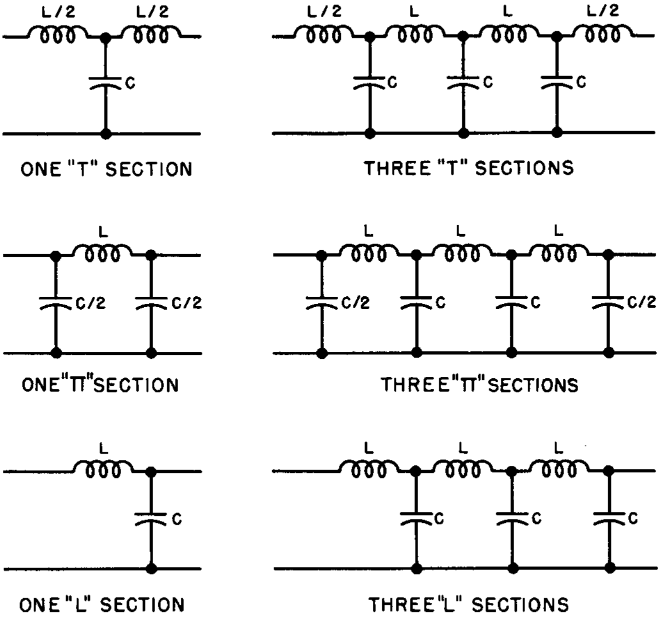


Fig. 27 Artificial line, generalized layout.

The most commonly used artificial lines are built in the form of "T" sections. (The manner in which this is done will be discussed later.) The smaller the sections or portions of the real line simulated, the more closely the characteristics approach those of a uniform physical transmission line.

Comparison of a transmission line to a rope may be made as an illustration of these principles. If a heavy rope of uniform construction is fastened at one end, with the other end held in the hand and moved up and down while maintaining some limited tension, a waveform will travel down the rope toward the far end. No appreciable variation in the waveform will be caused by a change in the frequency of motion. This is the equivalent of a uniform physical transmission line on which electrical waves are transmitted. If a lighter weight rope is similarly arranged, with small uniform weights at regular intervals along it to make it similar to the heavy rope, the wave shape moving down the rope will be similar in all details to that sent down the heavy rope. If, however, the rate at which the rope is moved is increased, the shape of the wave will tend to depart from that seen in the uniform heavy rope. It will be noticed that when the rate of moving the rope produces a form whose wavelength is long compared to the distance



ONE "T" SECTION

THREE "T" SECTIONS

ONE "π" SECTION

THREE "π" SECTIONS

ONE "L" SECTION

THREE "L" SECTIONS

Fig. 28 Artificial lines.

between the beads, the wave moves on the weighted line as it did on the heavy rope. But when the wavelength of the form is short compared to the distance between the weights, the wave becomes more and more distorted.

Now apply this to a radio transmission line. When, in an artificial line, the frequency that is applied to the line is low, the line behaves as if it were a uniform physical transmission line. But when the frequency is higher than one at which the line can so behave, the line does not act as a real line. The frequency at which the line stops acting as a real line may be computed from the following formulas:

$$f_{ch} = 2f_r \qquad f_r = \frac{1}{2\pi\sqrt{LC}} \qquad f_{ch} = \frac{1}{\pi\sqrt{LC}}$$

where f_{ch} is the frequency of changeover, and f_r is the resonant frequency of the elements of a single section. For frequencies below f_{ch}, the artificial line behaves as does a real uniform transmission line, but for frequencies above that critical frequency it does not.

It will be recalled that in a blocking oscillator, the timing can be controlled by imposing a pulse on the grid or other circuit. The pulse is preferably a square wave with sharp rise time or a pip spike. Sine waves give too slow a rise to provide accurate timing. To keep its shape, a pulse must preserve the amplitude and phase of all of its frequency components. Then, if a pulse is to be sent down an artificial line and used to time the operation of a blocking oscillator, the line must accomodate all of the frequency components of the pulse. With this requirement met, the line may be used to time the travel of a pulse; in fact, the exact location of the pulse on the line may be very accurately computed. This fairly rigorous timing of the pulse is an important factor and is used to determine when the blocking oscillator can again be made to conduct.

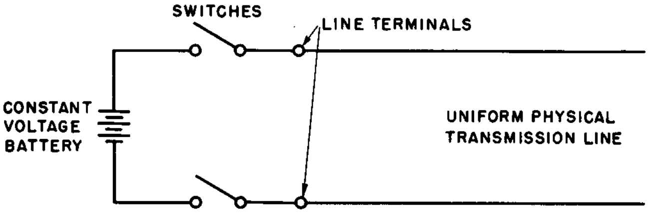


Fig. 29 Battery supply connected to a line.

The manner in which the pulse travels down the uniform physical transmission line may be described in the following manner. If a battery supply of constant voltage is connected to a line through switches, as shown in Fig. 29, and the switches are closed, the voltage of the battery appears at the start of the line.

When the switch is closed the applied voltage does not appear at all points along the line immediately. It takes time for a voltage "wave front" to move down the line. A "current front" also rides down the line, simultaneously with the "voltage front." The line on the negative side of the battery gains electrons; the line connected to the positive side of the battery loses electrons. This action takes place on both sides of the line in step with the progress of the wave fronts. As the electrons move in the line, magnetic flux lines surround the wire at the point of motion. This is the storing of energy in the inductance of the line.

The action taking place on a line is quite dissimilar to that in a small capacitor. For in a small capacitor the whole unit charges at one time, mainly because the amount of inductance is relatively small and no appreciable flux lines are established.

In a line, the progress of the voltage wave front is only as rapid as the progress of the electron movement, because the current has to establish the magnetic field, which in turn establishes the current in the next minute section of the line. It is in this manner that the voltage wave travels down the line simultaneously with the current wave, both being exactly in step. The traveling time is dependent upon the constants of the line and is quite determinable, especially as to the amount of time it takes a pulse to travel over the line or a portion of it. A line designed to provide delay of a wave is called a *delay line.*

The time it takes for the wave front to move through one section is the square root of the product of the inductance and capacitance of that section:

$$t = \sqrt{LC}$$

and the rate at which the wave front moves through one section

$$\text{(speed of movement)} = \frac{1}{\sqrt{LC}}$$

The characteristic resistance (the resistance presented by an infinite line) is the ratio of the voltage of the supply to the current flow if the line were replaced by a nonreactive resistor.

$$R_o = \frac{E}{I} = \frac{L}{C}$$

Although these formulas refer to a uniform physical transmission line, they also apply to an artificial line when the frequency is low compared to the frequency of changeover. When the frequency exceeds the frequency of changeover, no energy is transmitted along the line.

This is important because the transmission of a pulse, when used to provide timing operations, requires that the pulse have a steep wave front. The front depends upon the higher frequency components and if these are altered the pulse will have changed shape also. Therefore, the frequencies important to shaping the pulse must all be below the frequency of changeover if reshaping is not to occur.

Now let us consider the problems involved when a pulse travels down the line to the far end.

If a line were infinitely long, its characteristic resistance (R_o) were 500 ohms, and a battery of 200 volts were connected to the near end of the line through a 500-ohm resistor, the current flow would be the same as it would be if two 500-ohm resistors were connected to the battery supply. (0.2 ampere would flow.) This is shown in the diagrams of Fig. 30. If the switch connecting the battery is closed, a wave front of 100 volts and 0.2 ampere moves down the line.

This same set of conditions would apply if a shorter line were used (for example, one having a travel time of one microsecond and terminated in 500 ohms, its characteristic resistance). All of the energy of the wave front would be absorbed in the termination, exactly as it would be in an infinitely long line.

Again consider a real line. If the far end were open, and the line were long, up to say ten units of time, the following conditions would apply. At the moment the switch is closed to connect the battery to the line, the distribution of voltages would be the same as for an infinite line or a line terminated in its characteristic resistance, because the far end conditions apply only after the pulse reaches the far end. The charging of a line with an open end is shown in Fig. 31. Half the 200 volts would be distributed over the source resistance and half over the line characteristic resistance. The line voltage is 100 volts and the current 0.2 ampere. This would present a wave front, as previously explained, that would travel down the line, charging the capacitance of the line as it moved and building the magnetic flux lines about the conductors to develop a current waveform.

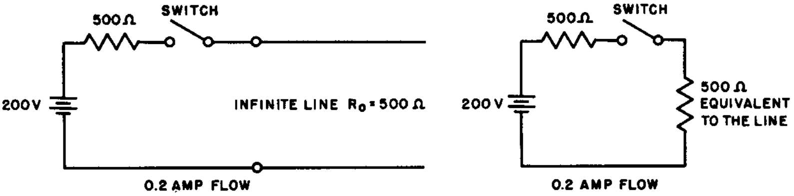


Fig. 30 Charging an infinite line.

When the end of the line has been reached, there is no more capacity to charge. Because the end of the line is open (has infinite resistance), the current must be zero. To make up this zero condition, there must be another 0.2-ampere wave starting from the end of the line and moving toward the battery supply end. With this current wave there is also a voltage wave. The 0.2-ampere current wave that traveled to the open end was set up by the inductance of the line. Now that it has reached the end of the line it causes the voltage to double and develop a counter current that reduces the line current to zero. This increased voltage at the open end and the decreased current constitute a reflected wave moving toward the battery. As this reflected wave moves it increases the charge on the line from 100 to 200 volts and reduces the current from 0.2 ampere to zero. When the wave has moved from the battery source to the far end and returned, it has measured a specific time interval, which can be used to institute action again in the blocking oscillator at a very accurately timed interval.

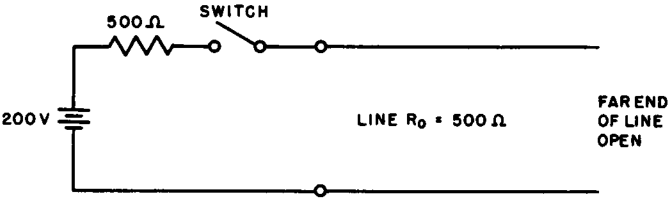


Fig. 31 Charging an open line.

When the end of the line is short-circuited instead of open, the line is left uncharged. When the wave front has reached the far end, the voltage (not the current, as in the open ended line) is zero. Then when the 100-volt 0.2-ampere wave front reaches the end of the line, a reflected pulse of reversed polarity must start back, discharging the line capacitance and causing a 0.4-ampere flow of current. That this is the case is obvious when Fig. 32 is viewed from the terminating condition. As the line is short-circuited, all of the battery voltage must appear across the source resistance of 500 ohms, causing a current flow of 0.4 ampere. Of course, the initial condition upon closing the switch was (as in the case of the open ended line) that the characteristic resistance of the line absorbed half of the voltage, so that only 0.2 ampere flowed.

We have seen that lines may be made either open ended or short circuit ended for terminations. It is also true that lines may be built with other terminations and act in manners dependent upon the type of termination.

We have seen that the characteristics of a physical transmission line may be simulated by artificial lines to produce a lag between the application of the pulse at the sending end and the arrival at the other end of the line. This delay interval is often used in radar and similar systems to secure delays up to about one microsecond. Longer time intervals are difficult to design because the number of sections needed to provide the delay would be very great, making the device cumbersome, and because there would be difficulty in establishing a sufficiently high changeover frequency.

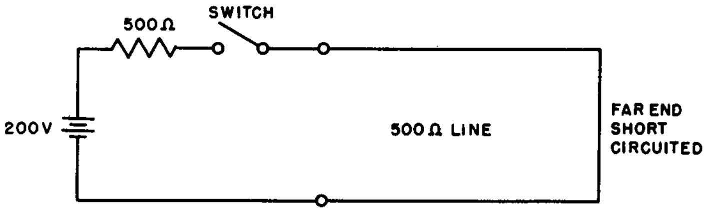


Fig. 32 Short circuited line.

A simple circuit arrangement to show the use of a delay line is given in Fig. 33. The constants are given only for the purposes of example in the use of the formulas. *They do not apply to any given practical unit.*

This figure shows two sections of a delay line of the π type, terminated in its characteristic resistance, 1400 ohms. The value of the resistor was computed from the formula:

$$R_o = \sqrt{\frac{L}{C}} = \sqrt{\frac{2}{1000} \times \frac{10^{12}}{1000}} = 1400 \text{ ohms}$$

The delay time for the two sections was computed from:

$$t = \sqrt{LC} = 2\sqrt{\frac{2}{1000} \times \frac{1000}{10^{12}}} = 2.8 \text{ microseconds}$$

In this simple arrangement it is assumed that the tube is operated with a plate resistance of 1400 ohms. This value can be verified from the characteristic curves of the particular tube used. When the tube conducts, the plate resistance terminates the near end of the line, and the 1400-ohm resistor terminates the far end of the line. In this way there are no reflections at either end of the line; all of the energy that travels the line is absorbed in the terminations.

Assume that a one-microsecond wave pulse is delivered to the grid of the tube to drive it from beyond cutoff to conduction. A negative one-microsecond pulse appears in the plate circuit of the tube. This is shown in the idealized waveforms of Fig. 34. Obviously, the start time of these two waveforms is the same. (The negative voltage pulse at the plate starts at the same instant as the activating grid voltage pulse.) The size of the plate voltage pulse can be determined from the supply voltage and a 1400-ohm load line on the tube characteristic. Assume that a 150-volt drop in plate voltage has occurred. Then 75 volts of it appears across the tube and 75 volts across the terminals of the line, because each has a value of 1400 ohms. This 75-volt pulse moves down the line to the far end termination, and arrives there 2.8 microseconds after it was initiated at the start of the line. The pulse is then taken off with the proper circuitry and used to measure a delay of 2.8 microseconds.

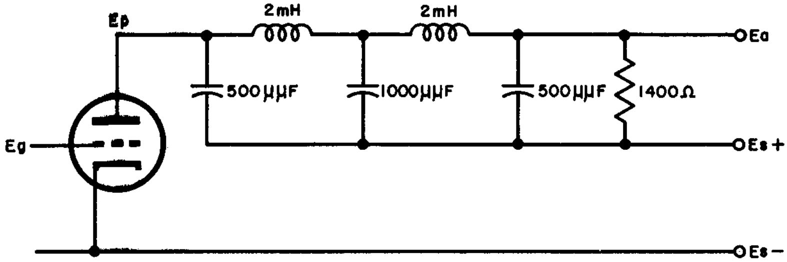


Fig. 33 Simple Delay line arrangement.

In Figs. 33 and 34 the line is terminated in its characteristic resistance. A similar arrangement, with a short circuit instead of a 1400-ohm termination, can be used to discriminate between pulses of various durations. This is shown in Fig. 35 and uses the same artificial line used in Fig. 33, except that here it is terminated in a short circuit.

A differentiation circuit of a 1-μf capacitor and a 10,000-ohm resistor is added to the circuit. The latter has a time constant of 0.01 microsecond computed as follows:

$$t = RC = 10^4 \times \frac{1}{10^{12}} = 0.01 \text{ microsecond.}$$

This is a highly idealized computation but it serves to show the principle involved. The time constant of 0.01 microsecond is short compared to the pulse duration of 5.6 microseconds (twice the delay time previously computed for the artificial line). In the latter, the pulse travels in two directions, making travel time twice the original 2.8 microseconds.

Assuming that pulses of any duration other than 5.6 microseconds are impressed on the grid of the tube, driving the grid from below cutoff to conduction, such a pulse would arrive at the plate circuit as a negative voltage and move down the line to the far end short circuit. As previously explained, when the pulse arrives at the end of a line terminated in a short circuit, the pulse reverses in voltage and moves back toward the original end. This is shown in the E_p waveform of Fig. 35. At the differentiator circuit voltage (E_L) is developed, marking (with spikes) the start and end of each pulse. It may be observed that these spikes of voltage E_L are all of the same size.

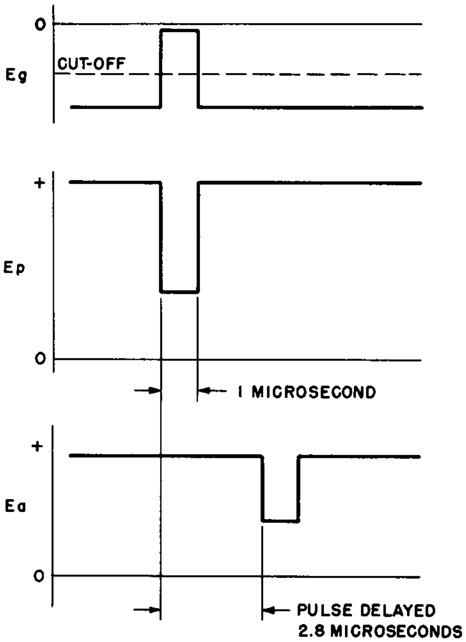


Fig. 34 Pulse delay.

Suppose, instead of pulses of duration other than 5.6 microseconds, a pulse of exactly 5.6 microseconds is impressed on the grid of the tube. The waveforms of Fig. 36 result. As previously shown, the plate voltage follows the timing of the grid pulse and has in addition the reflected pulse, which now joins the trans-

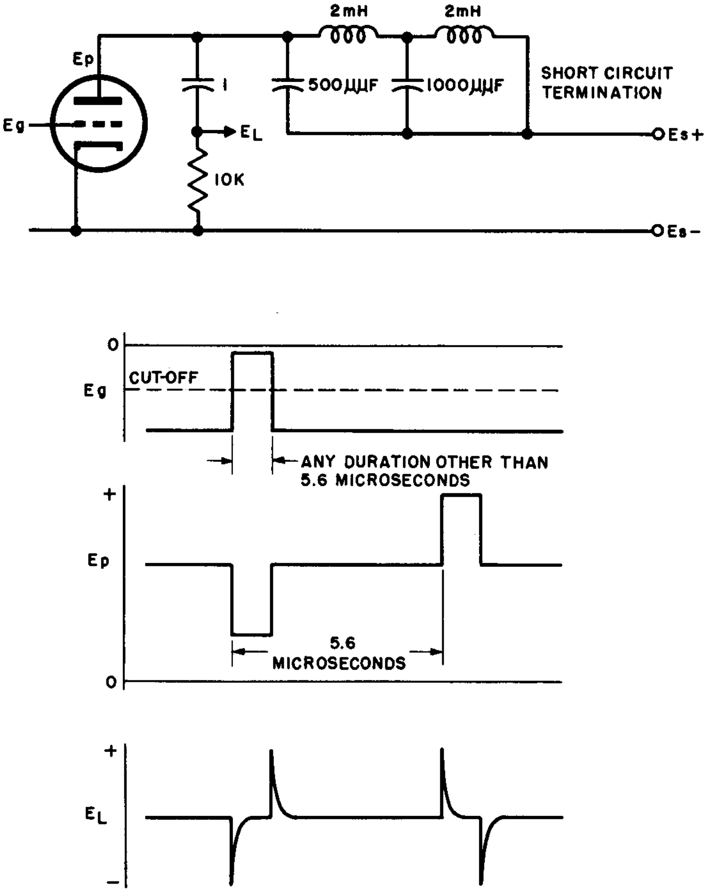


Fig. 35 Pulse duration discrinator. Differentiating circuit produces "spikes" (E_L) accurately marking time intervals between conduction pulses.

mitted pulse. This joined voltage, when differentiated, produces a spike twice as large as those formed from pulses of other duration. This larger voltage can then be directed to a circuit that passes only these larger pulses or spikes and thus discriminates against the pulses that have durations of other than 5.6 microseconds.

Another application of delay lines occurs in color television receivers. The signal is broken into three parts. These are the *Y* (luminance, brightness, or monochrome) signal, and the two chrominance signals, *I* and *Q*. The band of frequencies composing each of these three signals is different, and each is limited by pas-

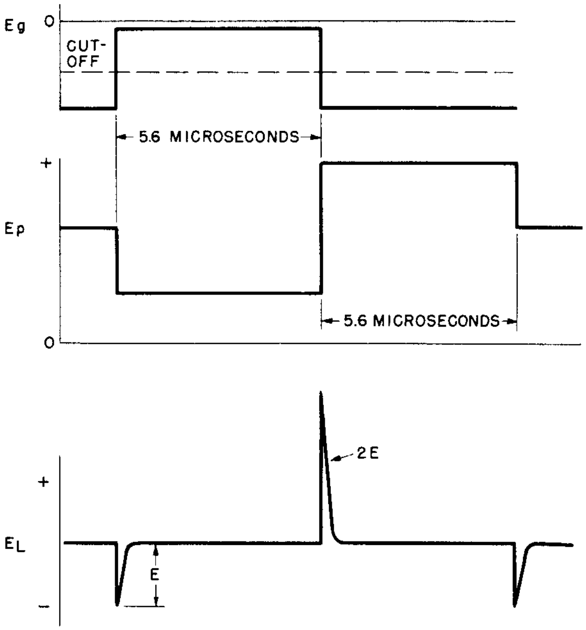
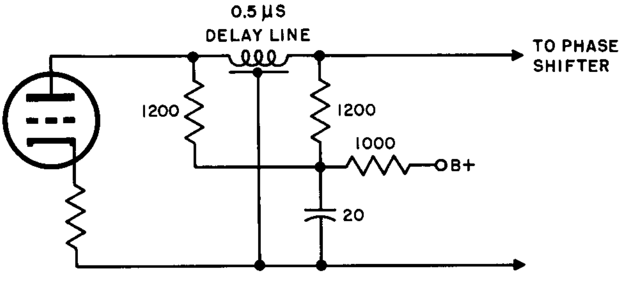


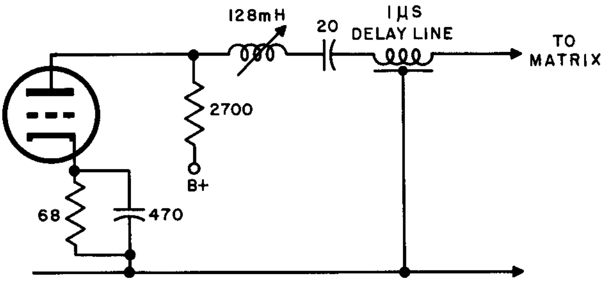
Fig. 36 Larger E_L spike produced when grid voltage pulse duration matches delay time in plate circuit.

sage through a filter. This is important because the time it takes for a signal to pass through its filter is inversely propertional to the width of its frequency band. For this reason, if the channels were not given different time delay corrections, the three signals would arrive at the picture tube screen at different times. To secure accurate superimpositions, the travel times of these signals, as they pass through their amplifiers, must be made the same. It should be noted that the *Q* channel has a bandwidth of only about 0.5 megacycle. Because it is narrower than either the *I* or the *Y* signal, its filter causes the greatest delay. The filter for the *I* channel, with almost a 1.5-megacycle bandwidth, delays its channel somewhat less. The *Y* channel, which has a band pass of from 3 to 4 megacycles, is the widest of the three channels and delays its signal the least.

This delaying of the signal in the channel amplifiers may be explained roughly by considering the band pass as a function of shunt capacitance. Narrow-channel filters have more capacitance than wider channel filters. As a signal passes through the channel,



I SIGNAL VIDEO AMPLIFIER



Y SIGNAL VIDEO AMPLIFIER

Fig. 37 Video amplifier circuits, illustrating use of delay lines.

it must pause to charge each capacitor. It therefore takes longer to pass through a narrow band channel.

To compensate for the delays introduced by the filters in the channels, artificial lines of various lengths or delays are used. In some receivers, the *Y* signal is delayed one microsecond, and the *I* channel a half microsecond. Since the *I* signal had previously been delayed a half-microsecond more than the *Y* signal (by the respective low pass filters), this causes them to emerge from their delay lines in phase with each other. By the same token, the *Y* and *I* signals are delayed as much as is the *Q* signal by its low pass filter alone. The *I*, *Y*, and *Q* signals thus all arrive at the picture tube grids at the same time. The exact amounts of delay vary with different receivers. The circuitry for one receiver is shown in Fig. 37.

Both of the delay lines shown in Fig. 37 are terminated at both ends to avoid any reflections. The delay lines resemble coaxial cable. By having each turn of the line near a shield, as shown in

Fig. 38, a line becomes effectively a multi-section line. Because there are effectively many sections, the changeover frequency is high. Therefore, negligible distortion occurs over the wide band of signal frequencies.

The use of delay lines has been discussed for several applications to show the wide use that is being made of them. In Fig. 39, two arrangements for using delay lines for the stopping of the blocking oscillator conduction pulse are shown. In each the delay line accepts the pulse at the start of conduction and the resulting reflected pulse returns after the predetermined delay and stops the conduction.

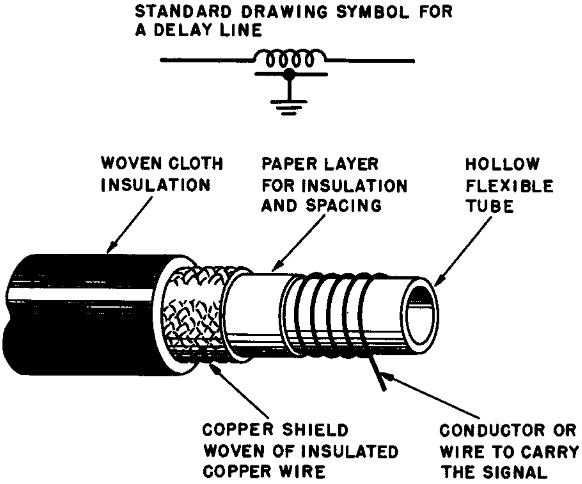
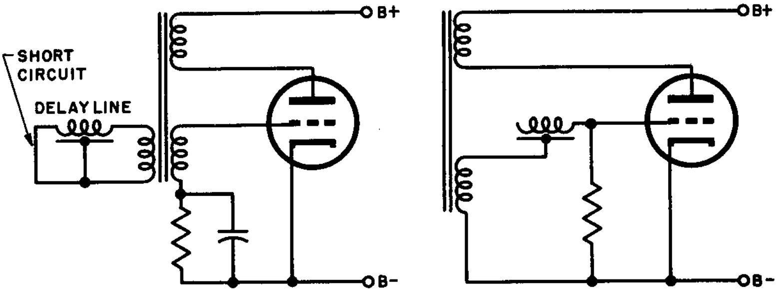


Fig. 38 Delay line construction.

These circuits are impedance-sensitive. The line must have impedance low enough to permit the tube to fire and high enough so that the characteristic impedance, rather than the capacitance of the line, controls the pulse duration.

31. One Shot Blocking Oscillator

As the name implies, in this circuit the grid is held below cutoff by the biasing battery *(E_c)* shown in Fig. 40. A large synchronizing pulse drives the tube to conduction, allowing the blocking oscillator to function in the manner previously described for one period only. The grid capacitor is charged in the normal blocking oscillator manner and loses its charge during the quiescent interval. But the grid bias E_c voltage then holds the circuit out of action until the next pulse arrives.



DELAY LINE WITH SHORT CIRCUIT TERMINATION

DELAY LINE WITH OPEN CIRCUIT TERMINATION

Fig. 39 Methods for terminating the conduction period.

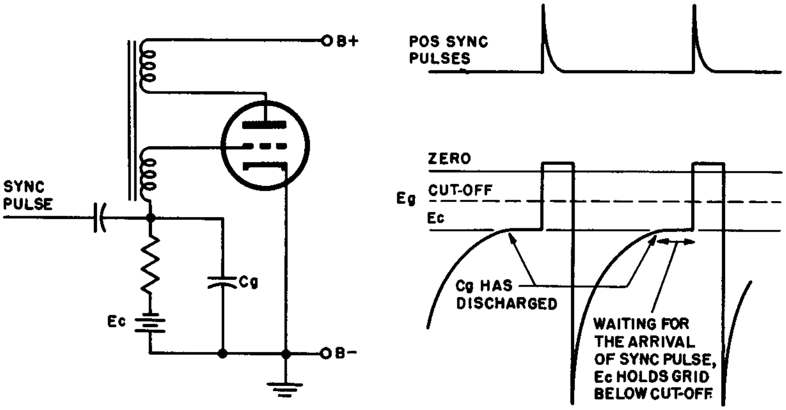


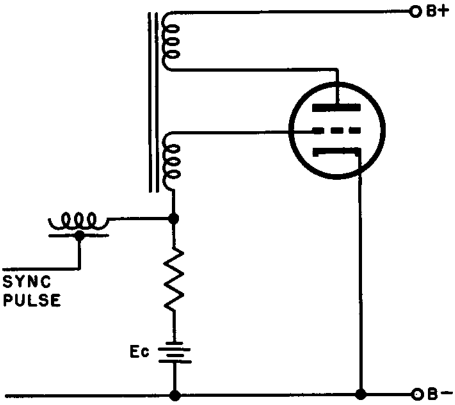
Fig. 40 "One-shot" blocking oscillator.

A variation of the one shot blocking oscillator is shown in Fig. 41. It is quite similar to the oscillator in Fig. 40, except that the input signal is delivered to a delay line with no far end termination.

A variation of the one shot blocking oscillator is shown in Fig. 41. It is quite similar to the oscillator in Fig. 40 except that the input signal is delivered to a delay line with no far end termination.

32. Counters

Counting circuits are used extensively in nuclear physics problems. Such applications involve counting pulses that have random time distribution. Large numbers of pulses must be counted to make for reasonable accuracy of the statistical average of assembled data. Rather than count for long periods of time it is more efficient to count for short intervals at high rates. For this reason, electronic counting circuits are used. These circuits produce output pulses, each representing a *group* of input pulses. The output pulses are then of slow enough repetition to operate a mechanical counter.



FiFg. 41 "One-shot" delay-line-controlled blocking oscillator.

Counters may be either of the energy-storage type or the sequence-operated type. Both can be designed for automatic recycling when a certain number of input pulses have been received. This may be called dividing because one operation occurs only after a certain number of pulses have been received, or it may be called counting because it informs of the number of occurences that have ben marked.

In Fig. 42, when the input signal (synchronizing pulse) consists of positive values, capacitor *C* is charged (made less negative) at the beginning of each pulse. The trailing edge of the input pulse is used to discharge the variable capacitor.

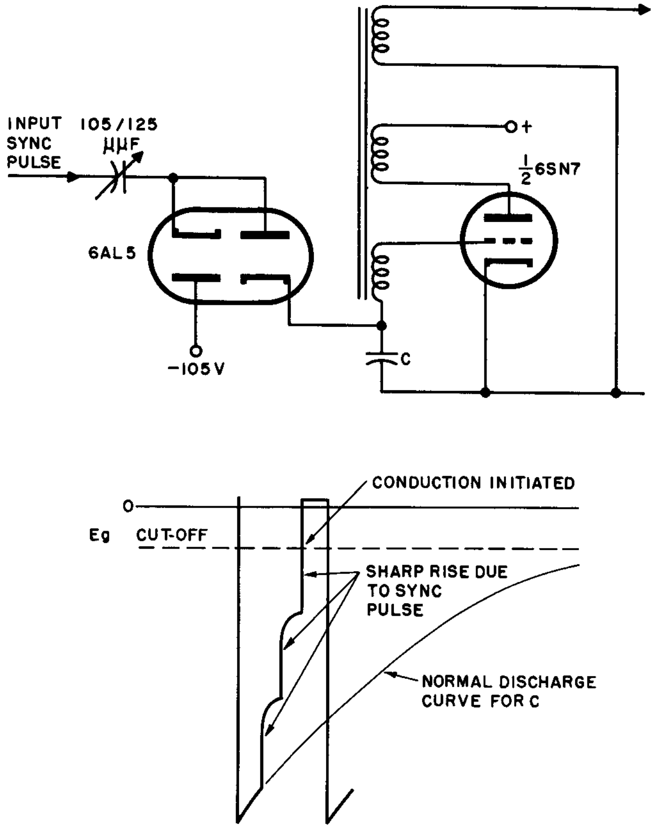


Fig. 42 Blocking oscillator counter.

It is assumed that at the beginning capacitor *C* is charged negatively through the oscillator conduction interval. In the curve shown, three pulses decrease the charge on capacitor *C* so that the tube fires again. Actually the number of pulses required to make the tube fire depends upon the magnitude of the pulses and their spacing. In the usual practical circuit the limit for the number of pulses that may be counted in this manner is usually five, although it is possible to arrange circuitry for a larger number of pulses with some sacrifice of accurate counting stability.

Design must also take into account the interaction between counter stages. The practical way of doing this is to calibrate the counter with a known source.

33. Dividers

Frequency division can be accomplished with similar circuits. One is shown in Fig. 43. In this circuit the input pulses are delivered to R_i to add to the voltage on the grid. The grid voltage in a freely-running blocking oscillator would be controlled by the voltage on capacitor C_g. But, in this case, when a pulse causes the grid voltage to become greater than the cutoff voltage of the tube, conduction is initiated. The frequency for the case in Fig. 43 is one-fifth of the original frequency.

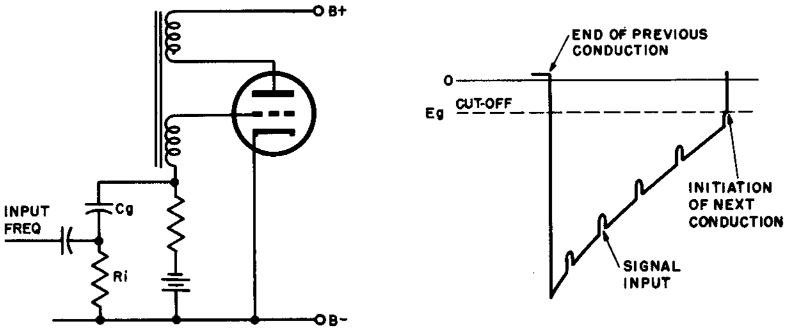


Fig. 43 Blocking oscillator divider.

It would have been possible in this circuit to feed the input signal through a transformer winding. It should be noted that the signal size does not cause the grid voltage to be changed except on the pulse that causes conduction.

This particular blocking oscillator is unstable because the voltage on capacitor C_g is dependent upon the conduction of the tube. It will be recalled that tube conduction is a function of heater temperature, cathode emission, ionization, etc., and is therefore difficult to predict. Compensation may be made in part for other variables by the selection of E_g battery voltage so that the difference in the size of the voltage resulting from adding the grid bias, the C_g voltage, and the signal voltage across R_i for two subsequent pulses will be greatest. This insures operation of the circuit on the correct pulse.

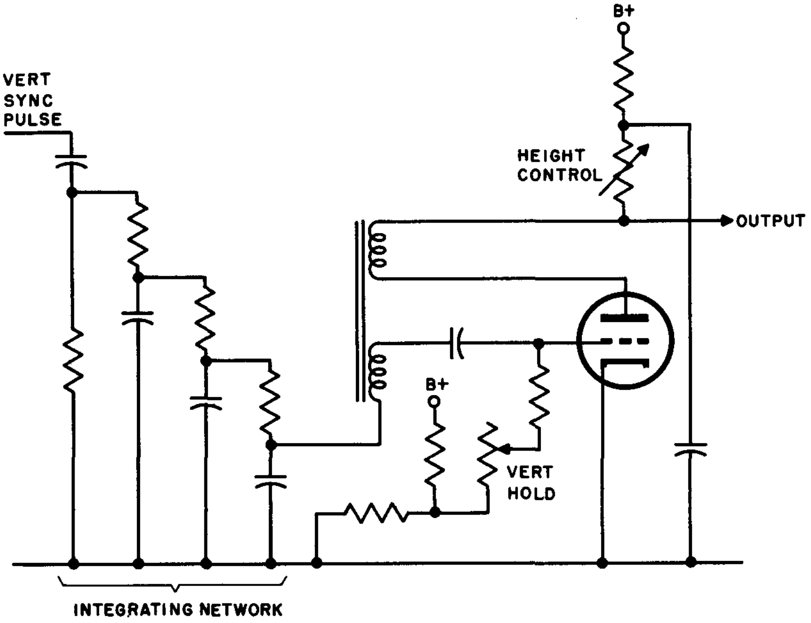


Fig. 44 Integrating circuit control.

34. Integration Control

An important application of integration control may be found in television receivers, particularly in the vertical sweep circuits. The synchronizing pulses are delivered to an integrating network as shown in Fig. 44. As the pulses charge the capacitors of the integrating network, the bias on the blocking oscillator changes, and when the sum of the several voltages in the grid circuit reaches the cutoff value, the tube conducts. Thus blocking oscillator action is initiated.

35. Review Questions

(1) State the chief difference or differences between monostable and astable oscillators.
(2) Of what use are delay lines in color television receivers?
(3) How does a divider circuit differ from a counter circuit?
(4) Why is it true that blocking oscillators are economical in operation?
(5) Describe the difference between parallel and series triggering.
(6) Describe two ways of controlling the recovery time of a blocking oscillator.

(7) Explain how a transmission line may be used to stabilize the repetition rate of a blocking oscillator. Why is this method not suitable for television applications?
(8) In a finite transmission line, what termination conditions are necessary if the wave front of the transmitted energy is to be completely absorbed?
(9) Give two reasons why the use of delay lines for delays of more than about 1 microsecond is not feasible.
(10) What is meant by the statement that circuits involving delay lines for controlling the blocking oscillator conduction interval "are impedance sensitive"?
(11) Explain the operation of a "one-shot blocking oscillator."
(12) Counters may be of the energy-storage type or the sequence-operated type. What are the differences between these two modes of operation?
(13) What is the function of an integrator network?

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