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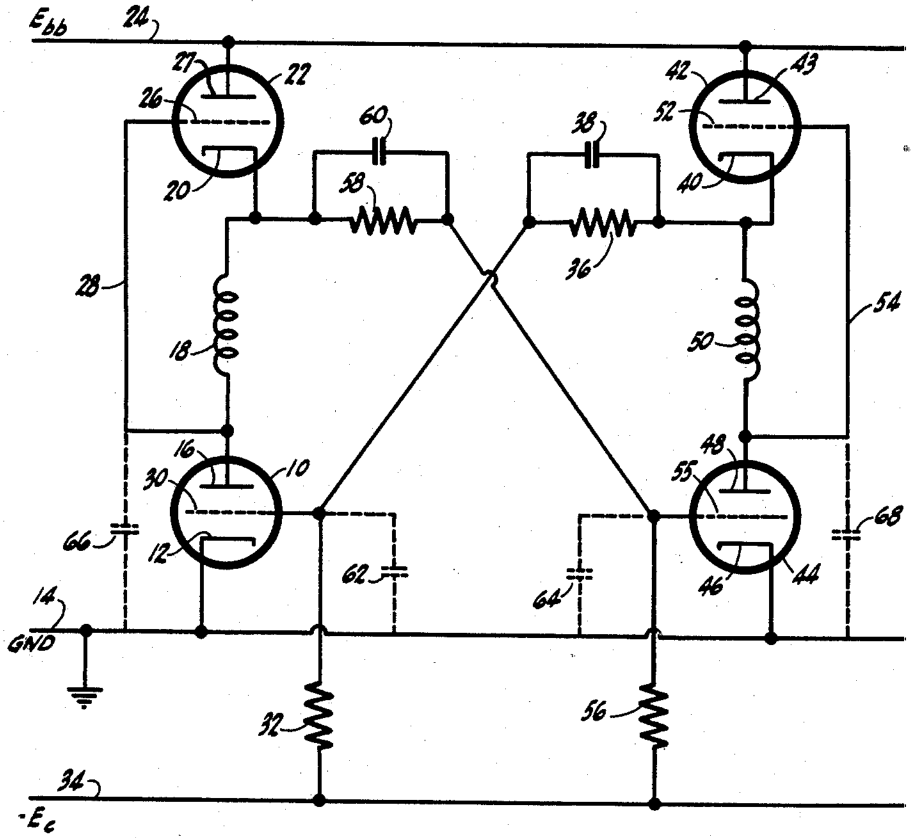

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FAST MULTIVIBRATOR CIRCUIT

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This invention relates to fast-acting multivibrators, which may be astable, with or without synchronization to external events, or monostable, or bistable.

In a multivibrator, two switching devices, e.g., electron tubes or transistors, conduct current alternately. An important characteristic of a multivibrator is the time required to complete the switching of current from one switching device to the other—i.e., the transition time between the two operating states of the multivibrator. The length of the switching or transition time has been a major limitation in the achievement of fast-acting multivibrators.

A faster-acting multivibrator may be devised for a variety of reasons; e.g., to achieve higher frequencies of operation; or to obtain pulse-type and other waveforms having shorter rise times, or shorter fall times, or both. An object of this invention is to provide improved, fast-acting multivibrators for such purposes.

A limiting factor affecting the switching or transition time in multivibrators is the time required to charge and to discharge circuit capacitances, including parasitic or stray capacitances. These capacitances tend to delay changes in voltage at various parts of the circuit, and thus tend to lengthen the rise and fall times of the voltage waveforms. This in turn lengthens the minimum period of the operating cycle. A more specific object of this invention is to provide improved multivibrators having novel means for charging and discharging circuit capacitances, and in particular certain of the unavoidable stray capacitances, with extreme rapidity.

According to the invention, a controlled, variable-impedance load device is connected in series with one switching device of the multivibrator, and, preferably, another such load device is connected in series with the other switching device. Each of the load devices is individually controlled, as hereinafter explained, to provide a low impedance while the voltage across the associated switching device is rising, so that circuit capacitances charge rapidly through the load device for effecting a short rise time in the voltage waveform, and to provide a high impedance while the voltage across the associated switching device is falling, so that circuit capacitances discharge rapidly through the switching device for effecting a short fall time in the voltage waveform. Multivibrators so constructed have been operated at significantly higher frequencies than any known to have been attained with prior multivibrators, with corresponding improvements in the rate of change in the voltage waveform at the transition points.

One example of carrying the present inventive concept into practice is described in conjunction with the accompanying drawing in which there is shown a multivibrator circuit incorporating therein the novel circuitry of this invention.

In the drawing, there is shown a multivibrator circuit of the astable or "free-running" type. Although the astable circuitry is shown, it will be readily appreciated that it is only by way of example and for purposes of illustration, whereas the inventive concept can also be

readily applied to monostable and bistable multivibrators. The changes required to apply the concept of the present invention to bistable and monostable multivibrators requires only modifications in the parameters of the circuit, well known to those skilled in the art, such varying the values of the bias resistors, etc.

In the circuit illustrated, there is a first multivibrator tube or switching device in the form of a vacuum tube **10**. The cathode **12**, defining one principal electrode, of the switching device or tube **10** is connected to a ground potential lead **14**. The other principal electrode, anode **16**, of the device or tube **10** is coupled through a first inductor **18** to one principal electrode, the cathode **20**, of a first load device in the form of a vacuum tube **22**. The other principal electrode, anode **27**, of the first load device or tube **22** is connected to a plate-supply voltage lead **24**, which may be at +300 v., and will be referred to as E_{bb}. The control electrode **26** of the tube **22** is connected to the anode of the switching tube **10** through a lead **28** interposed between the plate **16** and the first inductor **18**. The control grid **30** of the first switching tube **10** is connected through a bias resistor **32** to a negative voltage lead **34** (which can be referred to as $-E_c$) and is also connected through a first grid resistor **36** and first grid capacitor **38**, in parallel, to one principal electrode, the cathode **40**, of a second load device in the form of vacuum tube **42**, while the anode **43**, or other principal electrode, of the second load tube is connected to E_{bb}. This completes the first section of the circuit.

The second section of the circuit is similar to the first section. In the second section of the circuit, a second multivibrator tube or switching device, taking the form of a vacuum tube **44**, has one of its principal electrodes, cathode **46**, connected to the ground potential lead **14**. The other principal electrode, anode **48**, is connected in series with a principal electrode, cathode **40**, of second load device or vacuum tube **42** through a second inductor **50** interposed between the devices or tubes **42** and **44**. The control electrode **52** of the second load tube **42** is connected through lead **54** to the plate **48** of the second switching tube **44** at a point between the plate and the inductor **50**.

The control electrode **55** of the second switching tube **44** is connected through a second bias resistor **56** to the negative voltage ($-E_c$) and the control electrode **55** is also connected through second grid resistor **58** and second grid capacitor **60**, in parallel, to the cathode **20** of the first load tube **22**. From the foregoing description of connections, it is evident that the control electrode of each switching tube is coupled to the anode of the other switching tube, the impedances of inductors **18** and **50** being small compared to the impedances of load tubes **22** and **42**, and that the control electrode of each load tube is coupled to the anode of the switching tube in the same circuit branch.

The stray capacitances of the switching tubes **10** and **44** are shown in broken lines of the drawing. Among the stray capacitances indicated are a first input capacitance **62** from the control electrode **30** of the first switching tube **10** to the ground lead **14**, a second input capacitance **64** from the second switching tube **44** to the ground lead **14**, a first output capacitance **66** from the anode **16** of the first switching tube **10** to the ground lead **14**, and a second output capacitance **68** from the anode **48** of the second switching tube to the ground lead **14**.

In the operation of the circuit, with the multivibrator operating, assume that the rising portion or front of a signal or potential has been applied to the control electrode of the first switching tube **10**, which had been non-conducting, suddenly shifting the tube **10** from its non-conducting to a conducting state. The sudden flow of current to anode **16** creates a voltage drop across the first inductor **18**. This supplies a negative voltage between the control electrode **26** and the cathode **20** of the first load tube **22**, which tends to cut this tube off so that it appears as a high impedance. The impedance from anode **27** to anode **16** may then be expressed as $[(\mu+1)X_L+r_p]$. The value of the plate resistance r_p for the load tube **22** is very high when cut-off is approached and the reactance X_L of the first inductor **18** is multiplied by the amplification factor μ of the load tube. With a high impedance in the anode circuit, most of the electron current of the first switching tube **10** is available for dissipating the positive charge on the first output capacity **66** and for negatively charging the second input capacity **64**. The impedance path from the anode **16** of the tube **10** to the second input capacity **64** is quite low since the second grid capacitor **60** is essentially a short circuit at the high frequency considered. The reactance of the first inductor **18** is relatively low in such impedance path since the reactance of the first inductor is not multiplied by the amplification factor μ of the load tube **22**. The electron flow through the first inductor **18** to the second input capacity **64** creates a voltage drop which tends to hold the first load tube **22** non-conductive, and thus as a high impedance until the capacity **64** is charged. By substantially eliminating the retarding effect of these stray capacities, the circuit may be changed from the non-conducting to the conducting state in a very short time, and multivibrator operating frequencies up to 60 megacycles have been obtained.

As the first switching tube **10** is changing from its non-conducting to its conducting state, load tube **22** presents a high impedance, as explained above, and a rapidly decreasing or negative-going potential is applied to the control electrode **55** of the second switching tube **44**. Thus, tube **44** is changed from its conducting to a non-conducting state. A voltage is induced in the second inductor **50** by the decaying magnetic field of the inductor as the current through tube **44** and inductor **50** decreases driving the control electrode of the second load tube **42** positive with respect to the cathode **40**.

The decaying magnetic field tends to maintain an electron current flow in the second inductor **50**. Since the second switching tube **44** has been rendered non-conducting, the electrons are taken from the second stray output capacity **68**. The decaying magnetic field in the second inductor **50** also causes the second load tube **42** to have a low impedance, the low limit being the reciprocal of the transconductance of the tube. The first input capacity **62** is then effectively connected to the direct current supply (E_{bb}) through a low impedance. Thus, the circuit appears to have the characteristics of a cathode follower, and at the same time, have the attendant advantages of a low impedance output.

It will now be assumed that switching tube **44** is cut off and that first switching tube **10** is conducting. A switching signal, derived either internally or externally, is transmitted to the grid of the first switching tube **10** and tube **10** tends to cut off. Consequently, the current flowing through the first inductor **18** decreases, whereby the grid-to-cathode voltage of the first load tube **22** to become more positive. This action tends to "boot strap" the cathode potential of tube **22** upward toward E_{bb}. This action is then transmitted to the grid of the second switching tube **44**, making tube **44** conductive. The current in the second inductor **50** tends to increase, producing a voltage which tends to cut off the second load tube **42**, which in turn permits the cathode voltage of tube **42** to fall. As the cathode voltage of tube **42** falls, the first switching tube **10** is further driven toward cut off. It will be readily appreciated, that the entire action above described is regenerative, and the action is completed when tube **44** is cut off and tube **10** is conducting.

The action of the second inductor **50** and load tube **42** may be thought of as substantially aiding the switching speed as tube **44** becomes more conductive because not all of the electrons conducted by switching tube **44** flow through load tube **42** since load tube **42** is tending to cut off. These electrons may now "concentrate" on charging the stray capacitances **68** and **62** associated with the plate circuit of tube **44** and the grid circuit of tube **10** respectively.

The voltage induced across the first inductor **18** as tube **10** becomes less conductive makes the load tube **22** a low impedance for discharging the stray capacitances associated with the grid of switching tube **44**. It will be readily appreciated that the inductor **18** has an inductance and a resistance, L_{K1} and R_{K1} respectively, the sum of which is a complex impedance that may be represented by Z_{K1}. Likewise, the second inductor **50** has its inherent inductance and resistance, L_{K2} and R_{K2} respectively, the sum of which is a complex impedance represented as Z_{K2}. Therefore, the output impedance (Z_{out}) at the cathode **20** of tube **22** is expressed as

$$Z_{out}=\frac{r_{p2}(r_{p1}+Z_{K1})}{r_{p1}+r_{p2}+(\mu_2+1)Z_{K1}} \qquad (1)$$

where

Z_{K1}=total of R_{K1} and L_{K1}.
r_{b1}=plate resistance of tube **10**.
r_{b2}=plate resistance of tube **22**.
μ_2=amplification factor of tube **22**.

The voltage gain (without load) at the cathode of tube **22** over the signal applied to the grid of tube **10** is

$$\text{Gain}=\frac{-\mu_1(r_{p2}+\mu_2 Z_{K1})}{r_{p1}+r_{p2}+(\mu_2+1)Z_{K1}} \qquad (2)$$

where μ_1 equals amplification factor of tube **10**.

Therefore, it will be evident that the output impedance (Z_{out}) at the cathode of switching tube **22** is the ratio of the open-circuit voltage gain Equation 2 to the short-circuit gain, as set out in Equation 1.

Synchronization signals, from any source, not shown, may be introduced at the control electrode or the anode of the switching tubes following procedures well known to those versed in the art. Where triggering signals are to be used, the parameter values of the described circuit may be changed to provide either one or two stable states for the multivibrator following well-known techniques in the art.

It is further within the scope of this invention to utilize transistors in place of the electron vacuum tubes of the described circuit. This change is feasible by using those modifications well known to those skilled in the art.

What is claimed is:

1. In a multivibrator, the combination of four electron tubes each having an anode, a cathode and a control electrode, said four tubes being here designated for convenience the first switching tube, the first load tube, the second switching tube, and the second load tube, an inductor connected between the cathode of the first load tube and the anode of the first switching tube, forming a first circuit branch including two tubes in series with an inductor therebetween, another inductor connected between the cathode of the second load tube and the anode of the second switching tube, forming a second circuit branch including two tubes in series with an inductor therebetween, connections for applying voltage between the anode of the load tube and the cathode of the switching tube of each circuit branch, means coupling the control electrode of the switching tube in each branch to the anode of the other switching tube via the inductor cathode junction in the other branch for varying the current in each branch in inverse relation to the current in the other branch, and means coupling the control electrode of the load tube in each branch to the anode of

the switching tube in the same branch so that each load tube has a high impedance when the current in its circuit branch is increasing and a low impedance when the same current is decreasing.

2. The combination set forth in claim 1, wherein the coupling means between the two switching tubes comprises a resistor and a capacitor connected in parallel between the cathode of the first load tube and the control electrode of the second switching tube, another resistor and capacitor connected in parallel between the cathode of the second load tube and the control electrode of the first switching tube, means providing a negative potential relative to the cathodes of the switching tubes, and two resistors connected between the last-mentioned means and the respective control electrodes of the two switching tubes.

3. The combination set forth in claim 2, wherein the control electrode of the first load tube is directly connected to the anode of the first switching tube, and the control electrode of the second load tube is directly connected to the anode of the second switching tube.

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