SECTION 18

COUNTER CIRCUITS

PART A. ELECTRON-TUBE CIRCUITS

POSITIVE DIODE COUNTER.

APPLICATION.

The positive diode-counter circuit is supplied uniform input pulses, representing units to be counted, and produces a positive output voltage, the average value of which is proportional to the frequency of the applied pulses. Counter circuits are employed in the frequency-indicator circuits of electronic timing or counting devices.

CHARACTERISTICS.

Input pulses must be of constant amplitude and of equal time duration; a counter circuit must be preceded by limiting and shaping circuits to ensure uniform amplitude and width of input pulses.

Output-pulse polarity is positive; average d-c output voltage level is determined by input pulse-repetition frequency.

CIRCUIT ANALYSIS.

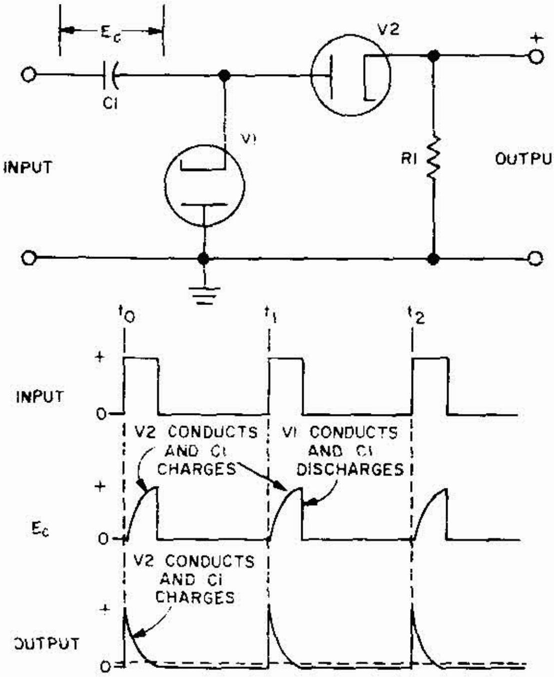
General. The positive counter circuit is used in frequency-indicator (timing or counting) circuits which depend upon the output pulse amplitude and time duration for accurate indications; therefore, the input pulses applied to the counter circuit must be of constant pulse amplitude and pulse width (time duration). The counter circuit is preceded by limiting and shaping circuits so that the only variable element in the counter-circuit output is the repetition frequency of the input signal, enabling input-frequency variations to be measured accurately. A relationship is thereby established between input frequency and average output voltage; as the input frequency increases the output voltage also increases and, conversely, as the input frequency decreases the output voltage decreases. Thus, the positive counter circuit, in effect, "counts" the number of positive-going input pulses and produces an average d-c output voltage which is proportional to the input repetition frequency.

The output of the positive counter circuit can also be used to produce positive trigger pulses to synchronize the frequency of blocking-oscillator or multivibrator circuits with the input pulse-repetition frequency. The basic positive counter circuit can be easily modified to change it to a step-by-step counter circuit (described later in this section) by substituting a capacitor for the resistor across the output terminals. This modified circuit is referred to as a **frequency divider**, because the output trigger frequency is usually made a submultiple of the input pulse-repetition frequency; the circuit is used in trigger-generator circuits of radar modulators and indicators.

Circuit Operation. A basic positive diode counter circuit is shown in the accompanying illustration, together with typical input and output waveforms. Capacitor C1 is the input coupling capacitor and also serves as a d-c blocking capacitor; resistor R1 is the load resistor across which the output voltage is developed. Electron tubes V1 and V2 are indirectly heated diodes; the filament (heater) circuit for the diodes is not shown on the schematic.

Initially, capacitor C1 assumes a charge (reference level) which is determined by the d-c voltage (if present) of the preceding stage. Once capacitor C1 is charged to the level of the applied d-c voltage, the circuit remains in a quiescent condition until an input is applied; the output voltage at this time is zero.

Pulses applied to the input of the counter circuit must have constant amplitude and equal time duration, since the counter circuit is intended to produce an output voltage which is proportional to the input pulse-repetition frequency. For the purpose of this discussion, assume that the input waveform shown in the accompanying illustration is applied to the input of the counter circuit.



Basic Positive-Diode Counter Circuit and Waveforms

When the positive-going leading edge of the input waveform occurs, the voltage rises suddenly. The charge on coupling capacitor C1 cannot change instantaneously; therefore, the plate of diode V2 becomes positive with respect to its cathode, and the diode conducts. Current flows through the series circuit consisting of load resistor R1 and diode V2 to charge the capacitor, C1. Since the charging current flows through the load resistor, R1, a pulse voltage is developed across the resistor and is supplied as the output of the counter circuit.

When the negative-going trailing edge of the input waveform occurs, the voltage drops suddenly. Once again the charge on coupling capacitor C1 cannot change instantaneously; therefore, a negative voltage appears across diode V1. (This negative voltage is equal to the charge previously obtained by capacitor C1 from the conduction of diode V2.) Since the cathode of diode V1 is now negative with respect to its plate, the diode conducts and discharges capacitor C1 to its initial value. The circuit then remains in a quiescent condition until another pulse is applied to the input.

If it were not for the fact that diode V1 discharges the capacitor each time a pulse is applied to the input, capacitor C1 would soon charge to the peak value of the input waveform as consecutive positive pulses were applied. As a result, no output would be obtained because the circuit would be rendered inoperative.

The charge time of capacitor C1 is determined by the value of resistor R1 and the low internal resistance of diode V2 when conducting. The discharge time of capacitor C1 is determined primarily by the low internal resistance of diode V1 when conducting. Thus, the time constant of the discharge path is always less than that of the charge path; therefore, within certain limits imposed by the R-C time constant and the applied pulse-repetition frequencies, the circuit is always in condition to accept the next positive-going input pulse.

From the discussion given in the previous paragraphs, it is evident that there is an average current flowing through resistor R1 whenever pulses are applied to the input of the circuit; also, a pulse voltage is produced across resistor R1 for each input pulse applied to the circuit. Thus, an average voltage is produced across resistor R1 which varies in accordance with the repetition rate of the input pulses; the average voltage increases as the input frequency increases, and vice versa. Since the output voltage level changes in proportion to changes in the repetition frequency of the applied input pulses, the output voltage can be fed to a succeeding stage which controls a suitable indicating device. The indicating device, in turn, can be calibrated in units of time, frequency, revolutions per minute, etc., based upon the relationship of output voltage to input frequency.

FAILURE ANALYSIS.

General. The positive diode counter circuit is a relatively simple circuit consisting of only four components—diodes V1 and V2, capacitor C1, and resistor R1. For this reason, failure analysis is somewhat limited.

Initially, the input signal to the counter circuit should be checked to determine whether it is present and has the correct amplitude and pulse width.

A visual check should be made to determine whether the filaments (heaters) of diodes V1 and V2 are lit and whether the filament circuit is complete. The diodes should be checked in a tube tester, or, as an alternative, diodes known to be good can be substituted and the operation of the circuit observed. If diode V1 is open and fails to conduct, capacitor C1 will charge to the peak value of the applied input pulse and, once the capacitor is fully charged, no output will be developed across the load resistor, R1; if diode V1 shorts, no output will be developed across the load resistor. If diode V2 is open or fails to conduct, no output will be developed across the load resistor; if diode V2 shorts, a positive output pulse will be developed across the load resistor, together with a small negative output pulse which will coincide with the negative-going trailing edge of the input waveform.

The counter circuit is normally preceded by limiter-shaper stages; therefore, in some cases a d-c potential exists at the input to the circuit. If coupling capacitor C1 should become leaky (or shorted), a voltage-divider action will occur. For this condition, it is likely that diode V2 will conduct at all times, and a d-c potential which is above normal will be developed across resistor R1. Capacitor C1 can be checked with a suitable capacitance analyzer; resistor R1 can be measured with an ohmmeter to determine its resistance.

NEGATIVE DIODE COUNTER.

APPLICATION.

The negative diode counter supplies a negative voltage output directly proportional to the repetition rate of incoming pulses. The negative diode counter is commonly employed in radar timing circuitry.

CHARACTERISTICS.

Input pulses must have uniform width and amplitude; only repetition rate may vary.

Usually preceded by limiting and shaping circuitry.

Develops a negative voltage output directly proportional to the repetition rate of incoming pulses.

Always returns to quiescent state between pulses.

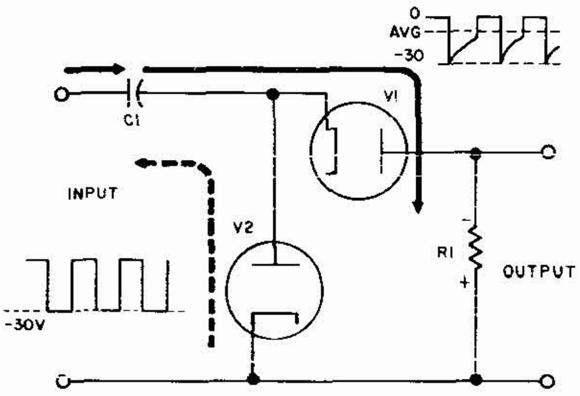
CIRCUIT ANALYSIS.

General. The negative diode counter circuit is used as a frequency indicating device in radar timing circuitry. With some modification, the diode counter may also be used as an f-m detector, a frequency divider or, when used in conjunction with a blocking oscillator or multivibrator, as a synchronizer.

Briefly, the negative diode counter furnishes a negative voltage output directly proportional to the repetition rate of the incoming pulses, provided pulse width and amplitude does not vary. If the repetition rate of the pulses increases, current flow through the load resistor also increases (occurs more times per second) and consequently the total voltage developed also increases.

Basically the diode counter utilizes the characteristics of a capacitor and diode to perform its function. The fact that a capacitor takes a finite time to charge and that a diode only conducts when its cathode is negative with respect to its plate, allows a voltage to be developed across the load resistor which is proportional to the repetition rate.

Circuit Operation. A basic negative diode counter, along with input and output waveforms, is shown in the accompanying schematic diagram.



Basic Negative Diode Counter

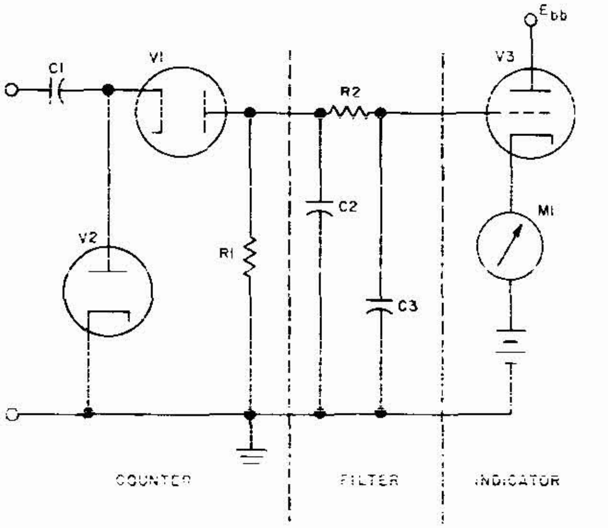
Capacitor C1 is the input coupling capacitor and R1 is the load resistor. Diode V1 is in series with the load resistor and it can easily be seen that as long as V1 conducts there will be an output, conversely, diode V2 is connected in parallel with the load, and as long as V2 conducts there will not be an output. Thus, V1 acts as an off-on switch, while V2 operates as a discharging diode. Since the circuit is to function as a frequency indicating device, it is necessary that pulse amplitude and duration remains the same for each pulse, with only the time between pulses (or repetition rate) being allowed to change. Hence, the negative diode counter is usually preceded by limiting and shaping circuits to ensure that each pulse is uniform.

As the negative leading edge of the initial incoming pulse appears at the input, capacitor C1 begins to charge; however, it is known from basic theory that a capacitor is unable to charge instantaneously. Consequently, at the first instant the signal is applied, the peak negative voltage appears on the cathode of V1, causing the tube to conduct. As the tube conducts, current flows through the load resistor, R1 to ground, developing a negative output voltage. As C1 charges, the voltage applied to the cathode of V1 becomes less negative and tube condition decreases, causing less voltage to be developed across load resistor R1, forming the curved portion of the output waveform as the capacitor charges.

As the positive-going trailing edge of the pulse is applied to the input, C1 again cannot instantly change in potential. Consequently, the cathode of V1 instantaneously becomes positive with respect to its plate (because of the charge on C1) and current flow through the diode and series load resistor ceases, instantly dropping the output voltage level to zero. Simultaneously, since V2 plate is now positive, V2 conducts discharging the capacitor. The circuit is returned to the initial quiescent condition with a discharged capacitor awaiting the next input pulse.

It is essential to remember that the circuit is returned to a quiescent condition each time the incoming input pulse returns to zero level, regardless of the pulse repetition rate. Referring to the schematic diagram it can easily be seen that charge current, (current flowing in the circuit while C1 is charging) flows through the combined resistance of V1 and R1, while discharge current (current flowing in the circuit while C1 is discharging) flows only through the conducting resistance of V2. For example, if we assign the load resistor and the conducting resistance of the identical diodes a resistance of 10 thousand ohms and 100 ohms, respectively, it may easily be seen that charge current flows through 10,100 ohms, while discharge current flows through a mere 100 ohms. Hence, the time constant of the charging cycle is very large with respect to that of the discharging cycle (approximately 100 to 1), and any voltage stored in C1 during charge is immediately discharged through V2, returning the circuit to its quiescent state.

From the preceding discussion it is evident that the voltage across the output varies in direct proportion to the input pulse repetition rate. Hence if the repetition rate (frequency) if the incoming pulses increases, the voltage across R1 also increases. In order for the circuit to function as a frequency counter, some method must be employed to utilize this frequency – voltage variation to operate an indicator. The following schematic diagram represents one simple circuit which may be used to perform this function. In this circuit the basic counter is fed into a low pass smoothing filter, which controls an electron tube with a cathode current meter calibrated is units of frequency.



Circuit Application

The negative output voltage developed across counter load resistor R1 is applied to the grid of V3 through the [illegible] prifilter network consisting of C2, R2 and C3. In this application the purpose of the filter is to smooth out any rapid increase or decrease in output voltage thus providing continuously smooth operation.

The filtered negative counter voltage is applied as bias to the grid of V3 and varies the plate current which flows through a meter in the cathode of V3. The meter is linearly calibrated on the front panel to indicate changes in current as a linear frequency change. For example, assume the circuit is operating and a specific frequency is indicated on the front panel meter. As the repetition rate of the pulses increases, the average voltage across the load resistor also increases and a larger bias is applied to V3. Plate current through V3 decreases, and as current through the meter decreases, a higher frequency indication is evident on the calibrated meter scale on the front panel of the equipment. If the applied frequency were to decrease, the opposite effect would occur and a greater plate current flow would produce a lower frequency indication on the meter.

FAILURE ANALYSIS.

No Output. Because the basic circuit only incorporates four components and operation is relatively simple, detailed trouble analysis is not necessary. If trouble is experienced with the circuit use an oscilloscope to check the input pulse train for uniform width and amplitude. Also check both diodes. If the trouble persists, check the dc resistance of R1 with an ohmmeter. Also check the coupling capacitor C1 with an in-circuit capacitor checker.

Weak Output. It a weak (or incorrect) output condition exists, check the input pulse train for uniform width and amplitude using an oscilloscope. Also check both diodes. Check the dc resistance of R1 using an ohmmeter and also check C1 with an in-circuit capacitor checker.

STEP-BY-STEP COUNTER.

APPLICATION.

The step-by-step counter is used as a voltage divider in electronic equipment when it is necessary to provide a stepped voltage output to a relaxation oscillator or any other device requiring a stepped voltage trigger.

CHARACTERISTICS.

Provides a stepped voltage output.

As the number of input pulses increases for one pulse of output, the counting accuracy decreases.

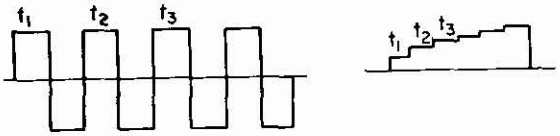
Utilizes two diodes.

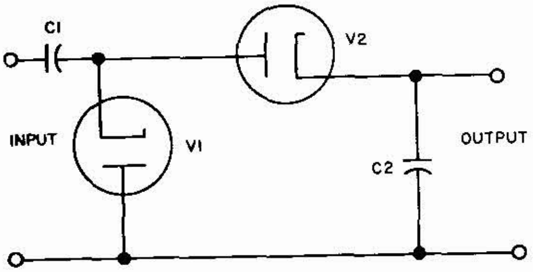
One step out occurs for each cycle of input.

CIRCUIT ANALYSIS.

General. The step-by-step counter (commonly referred to as simply a step counter) provides an output which increases exponentially in such a way that the output increases by a one step increment for each cycle of input. At a predetermined level, the output voltage reaches a point which causes some circuit, such as a relaxation oscillator, to be triggered.

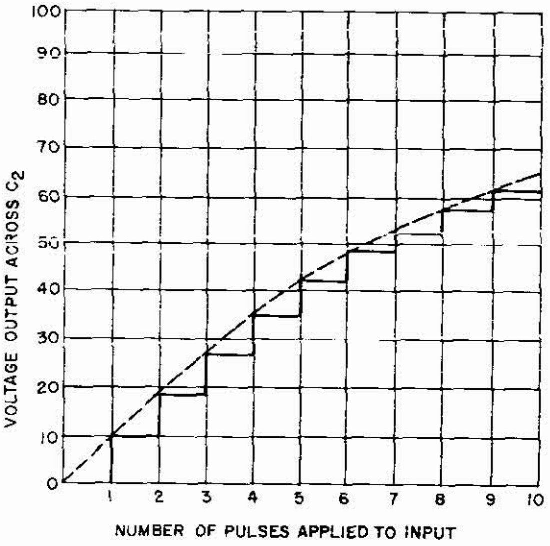
Circuit Operation. A schematic diagram of a step counter is illustrated in the accompanying figure.





Basic Step-by-Step Counter Circuit

With no signal applied at the input, there is no output. As the input signal is applied, and increases in a positive direction, the plate of V2 becomes more positive than its cathode, and the tube conducts. When V2 conducts, capacitors C1 and C2 begin charging. The action of the counter can be best understood by referring to the figure below. Since C2 is larger than C1 (for the sake of explanation, we will assume it to be ten times as large, and that the peak voltage of the input is 100 volts), C1 assumes nine tenths of the input voltage and C2 assumes only one tenth, or in this example, 10 volts. At time t_2, the input drops to a negative value, and V2 is driven into cutoff. At the same time, the cathode of V1 becomes more negative than its plate, and conducts, discharging C1. The charge on C2 remains, however, because it has no discharge path. Thus, there is a d-c voltage at the output which is equal to one tenth of the input. At time t_3, the input again increases positively, but this time V2 cannot conduct until the input becomes greater than 10 volts, the charge on C2. At this level, V2 conducts and C2 again charges to one tenth of the total available voltage. The total available voltage at this time, however, is no longer 100 volts, but 100 volts minus the 10 volt charge on C2. Thus, the first cycle of input produced a ten volt charge on C2, but the second cycle added only an additional 9 volts, which is one tenth the quantity of 100 volts minus the 10 volt charge on C2. By the same token, the third cycle adds only one tenth of 81 volts, which results from 100 volts minus the 19 volt charge on C2. Each additional cycle provides an exponential increase in the same manner. It is for this reason that the accuracy decreases as the ratio increases, because as the ratio becomes too great, the higher steps become almost indiscernable.



Waveform of Step Voltage

When the counter is used to trigger a relaxation oscillator, the oscillator bias is adjusted to cause triggering at a specific step. When the relaxation oscillator draws grid current, it discharges C2 and the cycle repeats. The step counter therefore becomes a frequency divider, supplying one output trigger for a number of input triggers.

As previously mentioned counting stability is dependent upon the exponential charging rate of capacitor C2. When it is desired to count by a large number, for example, 24, a 6:1 counter and a 4:1 counter connected in cascade may be used. A more stable method of counting 24 would be to use a 2:1, a 3:1, and a 4:1 counter in cascade. Most step counters operate on ratios of 5:1 or less.

FAILURE ANALYSIS.

No Output. A shorted V1, a non-conducting V2, an open or shorted C2, or a shorted C1 may cause a no-output condition to exist. Check both capacitors with an in-circuit capacitor checker.

Inaccurate Output Ratio. A low emission or shorted tube V1 or V2, or a leaky C1 or C2, can produce an inaccurate count. Check the tubes and if an inaccurate count still exists, check both capacitors with an in-circuit-capacitor checker.

PART B. SEMICONDUCTOR CIRCUITS

POSITIVE DIODE COUNTER.

APPLICATION.

The positive diode-counter circuit is used to count pulses and provide frequency indication. It is mainly used in electronic timing and counting devices, but it is sometimes employed as a frequency divider and in elementary types of computers.

CHARACTERISTICS.

Requires an input pulse of constant amplitude and time duration.

Provides a positive output voltage with an average d-c level that is proportional to the input pulse repetition frequency.

May be used to synchronize a blocking oscillator at a submultiple of original frequency.

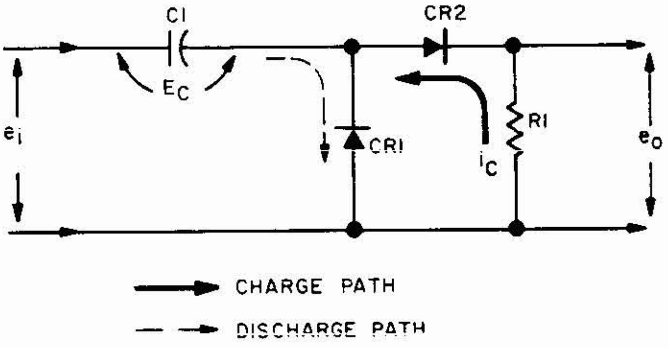
Requires an output circuit to provide a direct-reading output indication.

Requires that limiting and shaping circuits precede it.

CIRCUIT ANALYSIS.

General. The positive diode-counter circuit is used in timing or counting circuits which depend upon a proportional relationship between the output voltage and the number of input pulses. It may indicate frequency, it may count the rpm of a shaft or other device, or it may even register the number of operations. (This circuit is **not** the same as the binary or decade counter which is used in computers. The binary counter is discussed in Section 8, Part B, Multivibrator Circuits, and computer circuits are discussed in Section 19, Logic Circuits). The diode-counter establishes a direct relationship between the input frequency and the average d-c output voltage. As the input frequency increases the output voltage also increases; conversely, as the input frequency decreases the output voltage decreases. In effect, the positive diode-counter counts the number of positive input pulses by producing an average d-c output voltage which is proportional to the repetition frequency of the input signal. For accurate counting, the pulse repetition frequency must be the only variable parameter in the input signal. Therefore, careful shaping and limiting of the input signal is essential to ensure that the pulses are of uniform width, or time duration, and that the amplitude is constant. When properly filtered and smoothed, the d-c output voltage of the counter may be used to operate a direct-reading indicator. With slight modifications, the circuit can also be used to control a blocking oscillator and cause it to provide a trigger output which is synchronized at a submultiple of the original repetition frequency. (This modification is discussed under the Step-by-Step Counter circuit, which appears later in this section.)

Circuit Operation. The basic positive diode-counter circuit is shown in the accompanying illustration. Capacitor C1 is the input coupling and d-c blocking capacitor. CR1 and CR2 are semiconductor diodes, and resistor R1 is the load resistor, across which the output voltage is developed. For the purpose of circuit discussion, it is assumed that the input pulses are of constant amplitude and time duration, and that only the pulse repetition frequency changes.



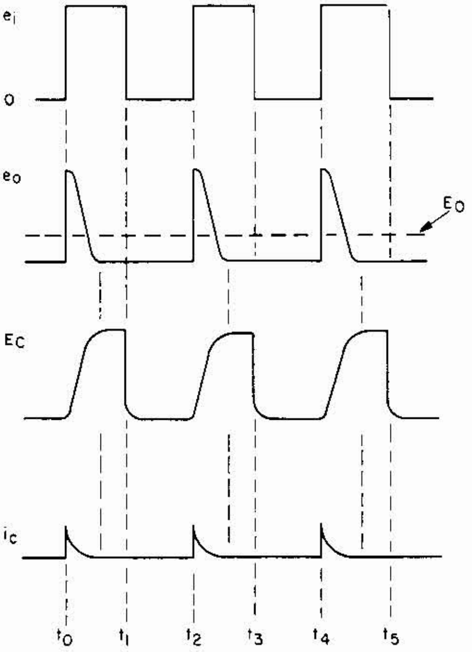
Positive Diode Counter

Once capacitor C1 is charged, it assumes a reference level as determined by the d-c voltage applied to the preceding stage, and the circuit remains in a quiescent condition until an input signal is applied. Prior to the application of the input pulse, the output voltage is zero.

As shown in the following illustration, at time t_o the positive-going input pulse is applied to C1 and causes the anode of CR2 to go positive. As a result, CR2 conducts and current i_c flows through R1 and CR2 to charge C1. Current i_c develops an output voltage (e_o) across R1 as shown in the illustration.

The initial heavy flow of current produces a large voltage across R1, which tapers off exponentially as C1 charges. The charge on C1 is determined by the time constant of load resistor R1 and the forward diode resistance, in series, times the capacitance of C_1. For ease of explanation, it is assumed that C1 is charged to the peak value before time t_1.

At time t_1 the input signal reverses polarity and becomes negative-going. Although the charge on C1 cannot change instantly, the applied negative voltage is equal to or greater than the charge on C1 so that the anode of CR2 is made negative, and conduction ceases. When CR2 stops conducting, output pulse e_o is at zero, and C1 quickly discharges through CR1, since its cathode is now negative with respect to ground (anode is grounded). Between times t_1 and t_2 the input pulse is again at zero level, and CR2 remains in a non-conducting state. Since the very short time constant offered by the forward resistance of CR1 and C1 is much less than the long time constant offered by CR2 and R1 during the conduction period, C1 is always completely discharged between pulses. Thus, for each



Circuit Waveforms

input pulse there is an exact amount of charge deposited in C1. For each charge of C1 an identical output pulse is produced by the flow of i_c through R1. Since this current flow always occurs in the direction indicated by the solid arrow, the d-c output voltage is positively polarized.

At time t_2 the input signal again goes positive, and the cycle repeats. The time duration between pulses is the interval represented by the period between t_1 and t_2 or between t_3 and t_4. If the input pulse frequency is reduced, these time periods become longer. On the other hand, if the frequency is increased, these time intervals become shorter. With shorter periods, more pulses occur in a given time and a higher average (d-c) output voltage is produced; with longer periods, fewer pulses occur and a lower output voltage is produced. Thus, the d-c output is directly proportional to the repetition frequency of the input pulses. If the current and voltage are sufficiently large, a direct-reading meter can be used to indicate the count; if they are not large enough to actuate a meter directly, a d-c amplifier may be added. In the latter case, a pi-type smoothing filter is inserted at the output of R1, to absorb the instantaneous pulse variations and produce a smooth direct current for amplification.

Consider now some of the limits imposed on circuit operation. Since the semiconductor diode has a finite reverse resistance, there is a flow of reverse current during the periods when the diode is supposedly in a nonconducting condition. Although this reverse flow is small at normal temperatures (on the order of microamperes), it increases as the temperature rises. Therefore, at high temperatures and high repetition rates, the average output voltage will tend to decrease because of the effects of diode CR2. Similarly, diode CR1 will tend to shunt some of the input signal to ground. Thus, the net over-all effect with increasing frequency is a progressive decrease in the linearity (that is, a reduction in the proportionality of input frequency to output voltage), and at very high repetition rates the circuit may become inoperative. Fundamentally this is a design problem which can be minimized by proper choice of components; it is mentioned here merely to indicate why semiconductor circuits sometimes do not perform as well as their electron tube counterparts.

FAILURE ANALYSIS.

No Output. A no-output condition may be caused by an open-circuited coupling capacitor, by defective diode CR2, or by a short-circuited condition (defective diode CR1, grounded CR2, or shorted load resistor R1). This condition can be easily resolved by a resistance check. Observing the proper polarity, check the diodes for a high reverse resistance and a low forward resistance. As a general rule, the reverse resistance should be 50K or greater, and the forward resistance should not be more than 10 ohms (these values vary with different types of diodes). Also, observe the input signal with an oscilloscope to make certain that is is present; the point at which the signal disappears will generally locate the defective component.

Low Output. If CR2 develops a high forward resistance, the output voltage will be reduced. If coupling capacitor C_1 becomes leaky, either a negative or a positive bias will be placed on CR2, depending upon the polarity of the previous stage collector or plate voltage. A negative bias on CR2 will prevent it from conducting, and will also act as a forward bias for CR1, causing it to conduct continually. Under these conditions, C_1 will constantly be discharging and the pulse will be reduced in amplitude (depending on the amount of leakage). Heavy leakage may result in no output at all, but it is more likely that the leakage will be light and only reduce the output. To check C1 for leakage, connect a d-c voltmeter between the output terminal of C1 and ground. If C1 is leaky, a constant negative or positive voltage will be present.

High Output. (For a positive leakage voltage through C_1, CR2 will conduct continually, and a higher-than-normal voltage will most probably be indicated.) If CR1 develops a high forward resistance, C1 will not be completely discharged at the termination of the input pulse. As a result, the output voltage will rise to a value equal to the dc potential applied to C_1 and remain constant regardless of pulse frequency changes.

NEGATIVE, DIODE COUNTER

APPLICATION.

The negative diode-counter circuit is used to count pulses and provide frequency indication. It is mainly used in electronic timing and counting devices, but it is sometimes employed as a frequency divider and in elementary types of computers.

CHARACTERISTICS.

Requires an input pulse of constant amplitude and time duration.

Provides a negative output voltage with an average d-c level that is proportional to the input pulse repetition frequency.

May be used to synchronize a blocking oscillator at a submultiple of original frequency.

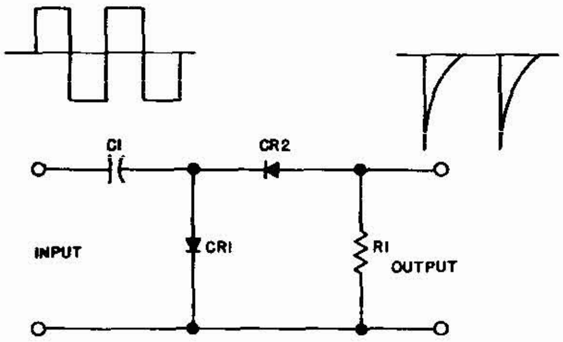
Requires an output circuit to provide a direct-reading output indication.

Requires that limiting and shaping circuits precede it.

CIRCUIT ANALYSIS.

General. The negative diode-counter circuit is used in timing or counting circuits which depend upon a proportional relationship between the output voltage and the number of input pulses. It may indicate frequency, it may count the rpm of a shaft or other device, or it may even register the number of operations. (This circuit is **not** the same as the binary or decade counter which is used in computers. The binary counter is discussed in Section 8, Part B, Multivibrator circuits, and computer circuits are discussed in Section 19, Logic Circuits in this Handbook.) The diode counter establishes a direct relationship between the input frequency and the average d-c output voltage. As the input frequency increases the output voltage also increases; conversely, as the input frequency decreases, the output voltage also decreases. In effect, the negative diode-counter counts the number of negative input pulses by producing an average d-c output voltage which is proportional to the repetition frequency of the input signal. For accurate counting, the pulse repetition frequency must be the only variable in the input signal. Therefore, careful shaping and limiting of the input signal is essential to ensure that the pulses are of uniform width, or time duration, and that the amplitude is constant. When properly filtered and smoothed, the d-c output voltage of the counter may be used to operate a direct-reading indicator. With slight modifications, the circuit can also be used to control a blocking oscillator and cause it to provide a trigger output which is synchronized at a submultiple of the original repetition frequency. (This modification is discussed under the Step-by-Step Counter circuit, which appears later in this section.)

Circuit Operation. The basic negative diode-counter is shown in the accompanying illustration. Capacitor C1 is the input coupling and d-c blocking capacitor.



Negative Diode Counter

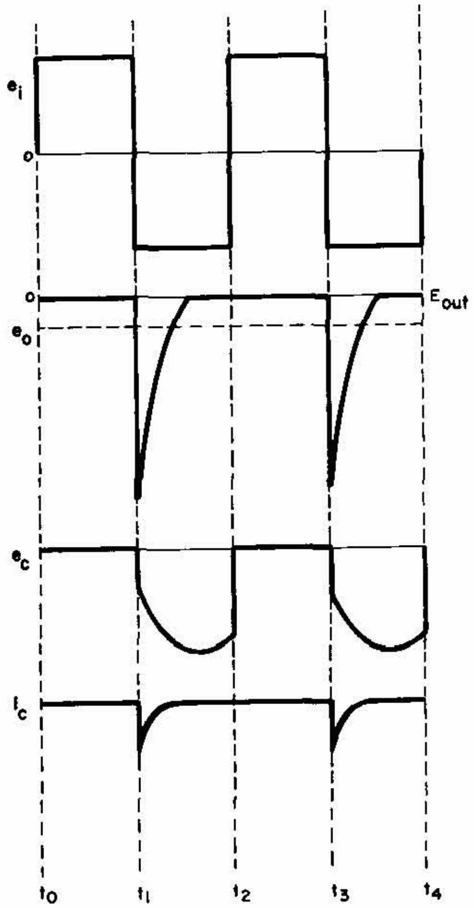
CR1 and CR2 are semiconductor diodes, and resistor R1 is the load resistor, across which the output voltage is developed. For the purpose of circuit discussion, it is assumed that the input pulses are of constant amplitude and time duration, and that only the pulse repetition frequency changes.

Once capacitor C1 is charged, it assumes a reference level as determined by the d-c voltage applied to the preceding stage, and the circuit remains in a quiescent condition until an input signal is applied. Prior to the application of the input pulse, the output voltage is zero.

As shown in the following illustration, at time t_0 the positive-going input pulse is applied to C1 and causes the anode of CR1 to go positive. As a result, CR1 conducts and charges C1.

C1 charges very rapidly because of its short time constant with CR1, but there is no output at this time because there is no current flow through R1. At time t_1, the input amplitude suddenly drops from maximum positive to maximum negative. The capacitor cannot discharge through CR1, because the anode of the diode is negative with respect to its cathode. The anode of CR2, however, is now positive with respect to its cathode and begins to conduct. The capacitor voltage and the applied voltage now aid each other, and they produce a current flow through CR2, down through R1, to ground, the result being as illustrated in the diagram. As C1 begins charging through R1, the voltage across R1, and hence the output voltage, begins to decrease towards zero at an RC rate, and at some time between t_1 and t_2, the capacitor is charged to the new voltage, producing zero volts at the output.

At time t_2 the input signal again goes positive, and the cycle repeats. The time duration between pulses is the interval represented by the period between t_1 and t_2, or between t_3 and t_4. If the input pulse frequency is reduced, these time periods become longer. On the other hand, if the frequency is increased, these time intervals become shorter. With shorter periods, more pulses occur in a given time and a higher average (d-c) output voltage is produced;



Circuit Waveforms

with longer periods, fewer pulses occur and a lower output voltage is produced. Thus, the d-c output is directly proportional to the repetition frequency of the input pulses. If the current and voltage are sufficiently large, a direct-reading meter can be used to indicate the count; if they are not large enough to actuate a meter directly, a d-c amplifier may be added. In the latter case, a pi-type smoothing filter is inserted at the output of R1, to absorb the instantaneous pulse variations and produce a smooth direct current for amplification.

Consider now some of the limits imposed on circuit operation. Since the semiconductor diode has a finite reverse resistance, there is a flow of reverse current during the periods when the diode is supposedly in a nonconducting condition. Although this reverse flow is small at normal temperatures (on the order of microamperes), it increases as the temperature rises. Therefore, at high temperatures and high repetition rates, the average output voltage will tend to decrease because of the effects of diode CR2. Similarly, diode CR1 will tend to shunt some of the input signal to ground. Thus, the net over-all effect with increasing frequency is a progressive decrease in the linearity (that is, a reduction in the proportionality of input frequency to output voltage), and at very high repetition rates the circuit may become inoperative. Fundamentally this is a design problem which can be minimized by proper choice of components; it is mentioned here merely to indicate why semiconductor circuits sometimes do not perform as well as their electron tube counterparts.

FAILURE ANALYSIS.

No Output. A no-output condition may be caused by an open coupling capacitor, by defective diode CR2, or by a short-circuited condition (defective diode CR1, grounded CR2, or shorted load resistor R1). These conditions can be easily resolved by a resistance check. Observe the proper polarity, and check the diodes for a high reverse resistance and a low forward resistance. As a general rule, the reverse resistance should be 50K or greater, and the forward resistance should not be more than 10 ohms (these values vary with different types of diodes). Also, observe the input signal with an oscilloscope to make certain that it is present; the point at which the signal disappears will generally locate the defective component.

Low Output. If CR2 develops a high forward resistance, the output voltage will be reduced. If coupling capacitor C1 becomes leaky, either a negative or a positive bias will be placed on CR2, depending upon the polarity of the previous stage collector or plate voltage. A positive bias on CR2 will prevent it from conducting, and will also act as a forward bias for CR1, causing it to conduct continually. Under these conditions, C1 will constantly be discharging and the pulse will be reduced in amplitude (depending on the amount of leakage). Heavy leakage may result in no output at all, but it is more likely that the leakage will be light and only reduce the output. To check C1 for leakage, connect a d-c voltmeter between the output terminal of C1 and ground. If C1 is leaky, a constant negative or positive voltage will be present.

High Output. (For a negative leakage voltage through C1, CR2 will conduct continually, and a higher-than-normal voltage will most probably be indicated.) If CR1 develops a high forward resistance, C1 will not be completely discharged at the termination of the input pulse. As a result, the output voltage will rise to a value equal to the d-c potential applied to C1 and remain constant regardless of pulse frequency changes.

STEP-BY-STEP COUNTER

APPLICATION.

The step-by-step counter is used as a voltage divider in transistorized equipment when it is necessary to provide a stepped voltage output to a relaxation oscillator or any other device requiring a stepped voltage trigger.

CHARACTERISTICS.

Provides a stepped voltage output which increases exponentially.

As the number of input pulses increases for one output pulse, the counting accuracy decreases.

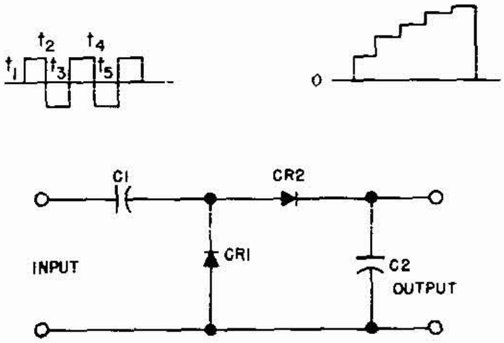
Utilizes two semiconductor diodes.

One step of output voltage is obtained for each cycle of input voltage.

CIRCUIT ANALYSIS.

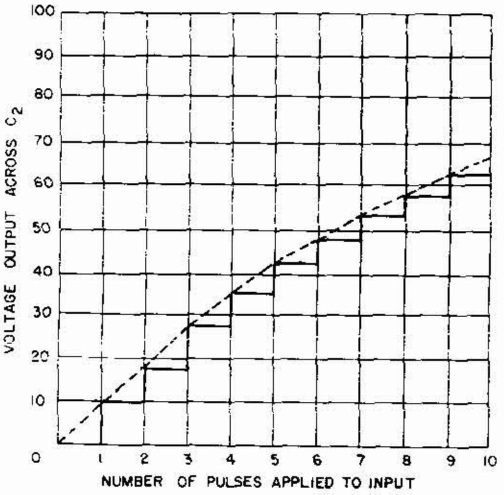
General. The step-by-step counter (commonly referred to as simply a step-counter) provides an output which increases exponentially in such a way that the output increases by one-step increments for each cycle of input. At a predetermined level, the output voltage reaches a firing point which causes some circuit, such as a relaxation oscillator, to be triggered.

Circuit Operation. A schematic diagram of a step-counter is shown in the accompanying illustration.



Basic Step-Counter Circuit

With no signal applied to the input, there is no output. As the input signal is applied, and increases in a positive direction, the anode of CR2 becomes more positive than its cathode, and the diode conducts. When CR2 conducts, capacitors C1 and C2 begin charging. The action of the counter can be best understood by referring to the following figure. Since C2 is larger than C1 (for the sake of explanation, we will assume it to be ten times as large, and that the peak voltage of the input is 100 volts), C1 assumed nine tenths of the input voltage while C2 assumes only one tenth, or in this example, 10 volts. At time t_2, the input drops to a negative value, and CR2 is driven into cut-off. At the same time, the cathode of CR1 becomes more negative than its anode, and it conducts, discharging C1. The charge on C2 remains, however, because it has no discharge path. Thus, there is a d-c voltage at the output which is equal to one tenth of the input. At time t_3, the input again increases positively, but this time CR2 cannot conduct until the input becomes greater than 10 volts, the charge on C2. At this level, CR2 conducts and C2 again charges to one tenth of the total available voltage. The total available voltage at this time, however, is no longer 100 volts, but 100 volts minus the 10 volt charge on C2. Thus, the first cycle of input produced a ten volt charge on C2, but the second cycle added only an additional 9 volts, which is one tenth the quantity of 100 volts minus the 10 volt charge on C2. By the same token, the third cycle adds only one tenth of 81 volts, which results from 100 volts minus the 19 volt charge on C2. Each additional cycle provides an exponential increase in the same manner. It is for this reason that the accuracy decreases as the ratio increases, because as the ratio becomes too great, the higher steps become almost indiscernible.



Waveform of Step Voltage

When the counter is used to trigger a relaxation oscillator, the oscillator bias is adjusted to cause triggering at a specific step. When the relaxation oscillator draws grid current, it discharges C2 and the cycle repeats. The step-counter, therefore, becomes a frequency divider, supplying one output trigger for a number of input triggers.

As previously mentioned, counting stability is dependent upon the exponential charging rate of capacitor C2. When it is desired to count by a large number, for example, 24, a 6:1 counter and a 4:1 counter connected in cascade may be used. A more stable method of counting 24 would be to use a 2:1, 3:1 and a 4:1 counter in cascade. Most step counters operate on ratios of 5:1 or less.

In actual theory, the reverse resistance of the diode will allow a portion of the charge of C2 to leak off. This leakage, however, in a practical circuit, will be negligible, because the diodes which are selected for use are types which will have a very high reverse resistance, so that the ratio between the charge time and the discharge time will be very large.

FAILURE ANALYSIS.

No Output. A shorted CR1, a non-conducting (open) CR2, an open or shorted output capacitor C2, or a shorted coupling capacitor C1, may cause a no-output condition to exist. Check both capacitors with an in-circuit capacitor checker. Check the diodes with an ohmmeter, being sure to observe the proper polarities, since an erroneous indication may otherwise be obtained. For the special case where the diode is not completely shorted, but reads a very low reverse resistance of, say 2000-ohms or less, the diode may be considered defective. In good condition, the diode reverse resistance should be 50,000-ohms or better, with a forward resistance of about 10 ohms (these values will vary from type to type).

Inaccurate Output Ratio. A low conducting, or a complete or partial short of CR1 or CR2, or a leaky C1 or C2, can produce an inaccurate count. Check both capacitors with an in-circuit capacitor checker. If an inaccurate count still exists, check both diodes with an ohmmeter, being sure to observe the proper polarities, since an erroneous indication may otherwise be obtained. For the special case where the diode is not completely shorted, but reads a very low reverse resistance of, say 2000-ohms or less, the diode may be considered defective.