SECTION 17

WAVESHAPING CIRCUITS

R-C DIFFERENTIATOR.

APPLICATION.

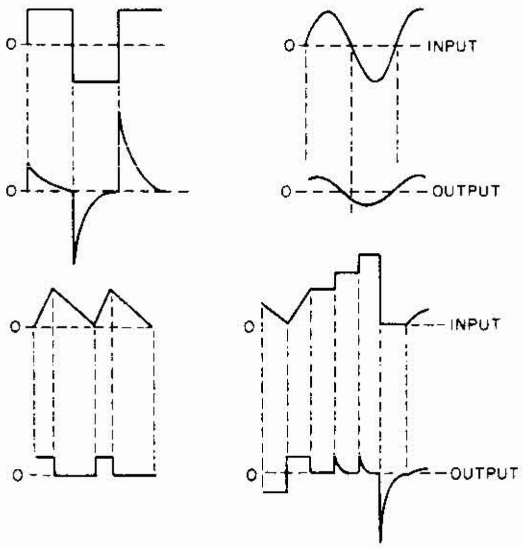
The R-C differentiator is used to produce a pip or peaked waveform, for timing or synchronizing purposes, from a square or rectangular-shaped input signal. It is also used to perform the electrical analog of differentiation for computer applications. It may also be used to produce specifically distorted waveshapes for special applications, such as trigger and marker pulses.

CHARACTERISTICS.

Input waveshape distorted (nonsinusoidal).
Short time constant R-C network used.
Functions essentially as a high-pass filter.
Output taken from across the resistor.
No amplification produced.

CIRCUIT ANALYSIS.

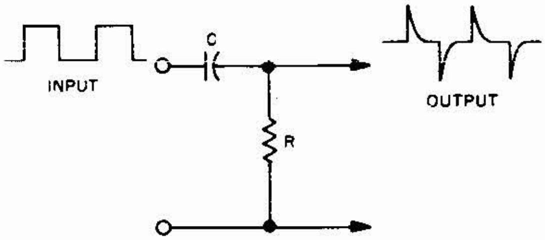
General. The output of a differentiator is proportional to the rate of change of the input signal. For a rising (positive-going) input the differentiator produces a positive pulse, for a falling (negative-going) input it produces a negative pulse, and, for a constant input it produces no output. The differentiator electronically simulates the mathematical operation of taking the first derivative. Second, third, and fourth derivatives may be obtained by cascading an equivalent number of differentiators. Theoretically the differentiator is accurate only when the output voltage is very small in comparison with the input voltage. In practice, this is achieved by using the shortest possible time constant for the highest frequency component involved in the waveform being differentiated. For computer, fire control, and similar operations, differentiation of the basic signal voltage produces an output voltage that represents the speed of the object, double differentiation yields the acceleration of the object, and triple differentiation yields the rate of change of acceleration. For timing and synchronizing use, a sharp pulse is produced for each leading edge and trailing edge of the input waveform. Although the circuit provides no amplification, for a square-wave input the peak output of the differentiator is twice that of the input signal, a positive pulse being produced for the positive leading edge and a negative pulse for the negative trailing edge. For other nonsymmetrical waveforms, since no d-c component is passed through the coupling capacitor, a peak output less than the maximum is obtained, and the output waveform is arranged about the average value as a zero axis. When differentiated, a triangular pulse will produce a rectangular output; a sinusoidal wave will not be changed in shape, but the signal will be shifted in phase and reduced in amplitude. The accompanying figure illustrates the various outputs for different input waveforms.



Differentiated Waveforms

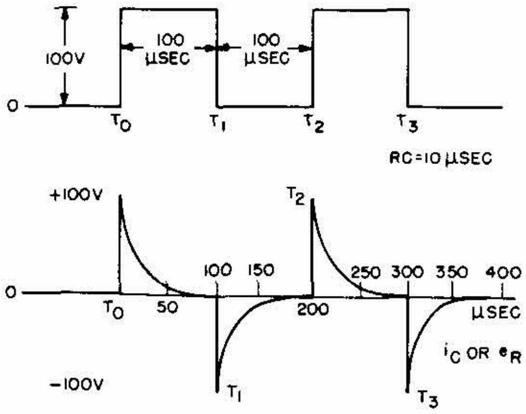
Circuit Operation.

The basic R-C differentiator is shown in the following schematic. The input is applied between the capacitor and ground, and the output is taken across the resistor. Usually this R-C combination constitutes the input or interstage coupling network; especially where R-C coupling is used.



Differentiating Network

When the reactance of capacitor C at the highest frequency to be passed is neglibible, the entire input voltage is applied across the resistor. The capacitor quickly charges on the leading edge of the input pulse, and this high-frequency signal is passed, essentially without attenuation, to the input of the following amplifier or control stage. When the time between the leading and trailing edges of the input signal is relatively long (greater than 10 time constants), the capacitor charges, producing a peaked waveform, and remains in the charged condition until the trailing edge occurs. The trailing edge then allows the capacitor charge to be impressed across the resistor, and the capacitor discharges, producing another peaked waveform; however, this time it is of reversed polarity, after which it remains at rest until the next input pulse. The passage of the charging current through resistor R develops the voltage which is the output of the differentiator. An exaggerated version of the differentiator current and voltage waveforms is shown in the following illustration.



Differentiator Current and Voltages

The exact functioning of the differentiator is easy to understand by considering the charge on coupling capacitor C, shown in the schematic drawing. Referring to the current and voltage waveforms of the preceding figure, assume a 100-microsecond square-wave input, with a 100-volt amplitude. At time t_0, capacitor C is assumed to have no charge, and the leading edge of the square wave is applied. Since the charge, or voltage on the capacitor cannot change instantaneously, but takes a finite time, a high current flows through resistor R and creates a large pulse of voltage, which is in effect the leading edge of the square wave passed through the capacitor. During the interval between time t_0 and t_1, the capacitive charging current through C decreases in an exponential manner. The time required to charge or discharge the capacitor is determined by the circuit time constant. In this instance, assume that C is 100 picofarads and R is 100 kilohms; then the RC time constant is 10 microseconds. From the universal time constant chart in Section 2, it is seen that in 50 microseconds (5 time constants) the capacitor will have charged to 99.3% of the maximum possible charge, and that in 100 microseconds (10 time constants) a complete charge (or discharge) is assured. The current and voltage illustration shows the capacitor charging current for the 100-microsecond period (the figure is also a representation of the output voltage of the differentiator). Between t_0 and t_1 the square wave amplitude is constant and, since there is no change, the differentiator does not produce an output. The capacitor voltage changes from zero toward a maximum value of 100 volts (assuming no losses); the charging voltage is bucked by the capacitor voltage, thus producing the exponential charging rate. By the end of period t_1 the capacitor is fully charged and the negative-going trailing edge of the input signal occurs, causing an instantaneous high flow of discharge current through R. Between t_1 and t_2 capacitor C discharges in a manner similar to that of the charge, and the negative differentiated spike is produced across R. To be a true mathematical derivative of the input voltage, the capacitor voltage must equal the input voltage, and the current will be proportional to the derivative of the input voltage. This condition can be approached by reducing the value of R until practically all of the voltage developed appears across the capacitor instead of the resistor. At this time R is practically a short circuit and no output exists. Therefore, in practical differentiators, the time constant is reduced to as small a value as possible. Usually a time constant of 1/10th the period of the input pulse produces satisfactory output spikes. The effect of reducing the time constant can be understood by referring again to the preceding illustration of current and voltage waveforms.

Assume a time constant of only 1 microsecond; then in 10 microseconds the capacitor is fully charged, and the circuit rests for 90 microseconds until another change occurs. Actually, since usually only the top portion of the differentiated signal is selected for use, the approach to a true thin spike is practically achieved and the effective charging period occurs for only a few microseconds. For timing, marker and synchronizing uses, the width of this spike in some cases is not very critical, since the leading edge rather than the trailing edge is used. Where the trailing edge is used, the width of the spike is important. In computer use, where the mathematical analog is important, both R and the time constant are reduced to the lowest possible value. Practical limitations imposed on these values are the input and output resistances of the stages between which the differentiator is connected, and stray capacitance across the differentiator output produces a capacitive voltage divider effect, which limits the output voltage to a lower value than the applied input voltage. Also, when the percentage change in capacitance is on the order of 20% of the value of C, the RC time constant is affected. With the example given in the figure, a stray capacitance of 20 picofarads (because of wiring, parts placement, etc) is one-fifth (or 20%) of the value of C, and this would effectively change the charge time. Or, considering the stray capacitance as producing a frequency-selective effect, it is clear that the high frequencies in the input signal (which cause the effect that the differentiator utilizes) would tend to be bypassed to ground, leaving only the low frequencies, which have a slow rate of change and produce little effect on the differentiator.

FAILURE ANALYSIS.

No Output. Since only two components are involved, it is evident that only an open circuit at the input, or a short circuit at the output, could produce a no-output condition (open capacitor or shorted resistor).

Distorted Output. Only a change in component values or associated stray capacitance and resistance values could change the time constant and waveshapes. Distorted output is usually caused by improper input signals. When checking the waveform at the differentiator, the effect of the shunt resistance or capacitance produced by the test instrument input should be considered. When distortion is discovered in the following tube circuits, it is probably caused by improper action in these circuits. A direct check of the output as compared with the input to the differentiator using a high-impedance oscilloscope, will indicate whether the circuit is performing properly. A shorted capacitor or an open resistor would cause the output to be a duplicate of the input (no differentiation taking place).

R-L DIFFERENTIATOR.

APPLICATION.

The R-L differentiator is used to distort an applied waveform (such as a square wave) into a peaked wave for the purpose of providing trigger and marker pulses. It is also used to electronically perform the mathematical function of differentiation in computers, and for separating the horizontal sync in television receivers.

CHARACTERISTICS.

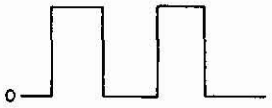
Produces distortion of the input waveform.
Has a short time constant.
Output is taken from across inductor.
Functions essentially as a high-pass filter.
Output is similar to the output of an R-C differentiator.

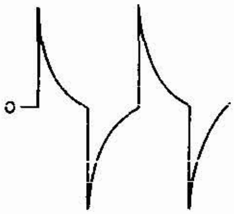
CIRCUIT ANALYSIS.

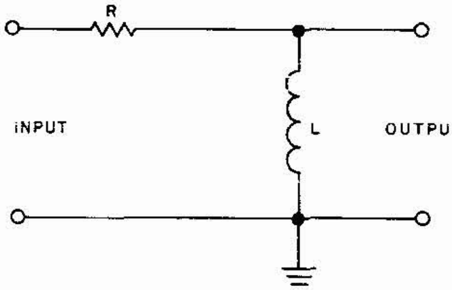
General. The output of a differentiator is proportional to the rate of change of the input signal. For a rising (positive going) input the differentiator produces a positive pulse, for a falling (negative going) input it produces a negative pulse, and for a constant input it produces no output. The differentiator electronically simulates the mathematical operation of taking the first derivative. Second, third, and fourth derivatives may be obtained by cascading an equivalent number of differentiators. Theoretically the differentiator is accurate only when the output voltage is very small in comparison with the input voltage. In practice, this is achieved by using the shortest possible time constant for the highest frequency component involved in the waveform being differentiated. For computer, fire control, and similar operations, differentiation of the basic signal voltage produces an output voltage that represents the speed of the object, double differentiation yields the rate of change of acceleration. For timing and synchronizing use, a sharp pulse is produced for each leading edge and trailing edge of the input waveform.

Circuit Operation. A schematic of a basic R-L differentiator is shown in the accompanying illustration.

The input is applied between the resistor and ground, and the output is taken across the inductor. The time constant (in seconds) of an R-L circuit is found by dividing the inductance (in Henrys) by the resistance (in ohms) TC=L/R. Thus to shorten the time constant of an L-R circuit it is necessary to increase resistance R rather than decrease R as in the R-C circuit. The counter emf produced by the inductor causes it to have the property of opposing any change in current flow. By referring to the universal time-constant chart in Section 2 of the Handbook, it is noted that the inductor voltage decreases from the applied voltage at an exponential rate to approximately zero at the end of 5L/R time intervals. Likewise, when the source is removed, a counter emf of opposite polarity is induced in the inductor, and this tends to keep current flowing. This voltage also decreases at an exponential rate. Thus, if a square pulse having a time duration of 5L/R time intervals is applied, a peaked waveform appears as the output voltage. This output waveform has a shape that is similar to the output obtained from an R/C differentiator.

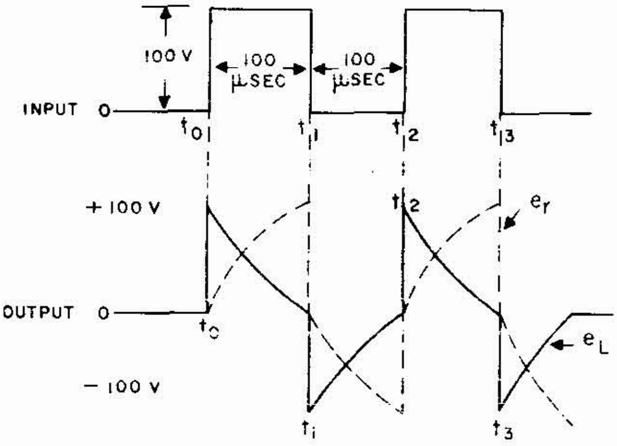






Basic R-L Differentiator Circuit

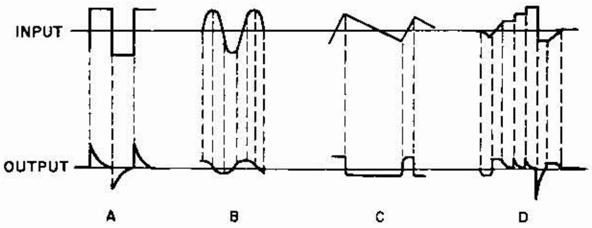
The exact functioning of the differentiator may be easier understood by referring to the accompanying illustration.



Differentiator Waveforms

With a square wave pulse of 100 volts amplitude applied as an input signal at time t_0, the output is a positive 100 volts spike. At this time there is no voltage drop across resistor R, since the inductive effect of L is to build up instantly a back emf that equals the applied signal and prevents instant current flow through the inductor. Between time t_0 and t_1 current begins to flow through inductor L and a small voltage drop is developed across resistor R. As the current flow through R increases, the voltage drop (shown in dotted lines in the waveform figures) increases. Meanwhile, the voltage developed across the inductor, e_L, is decreasing, and, since the output is taken across L, it is also decreasing (the decrease of voltage across coil L represents the voltage used in building up a magnetic field around L). The sum of the voltage drops across R and L equal the applied voltage. The current through inductor L increases exponentially and the voltage across resistor R increases, likewise. Since the time constant assumed in the illustration is 10 microseconds and the pulse width is 100 microseconds the steady-state condition is reached before the pulse ends. Since there now is no change in current, there is no voltage developed across the inductor and the output voltage is zero. At time t_1 the trailing edge of the input pulse occurs and drives the signal in a negative direction. Instantly a negative 100 volt spike appears across L and at the output. At the same time, the field around the coil collapses and produces a current through L in the opposite direction. During time t_1 to t_2 the negative voltage across the inductor decreases exponentially while the current increases exponentially. As the current flow through R increases, the voltage drop across it, likewise increases, and the sum of the voltage drops across R and L equals the applied voltage. With the 10 microsecond time constant and 100 microsecond pulse width, the steady state condition is again reached before the pulse ends. Since there now is no change in current, there is no voltage developed across the inductor and the output voltage is zero. At time t_2, the positive-going leading edge of the pulse appears and the cycle repeats.

The accompanying illustration shows the differentiated output waveforms for several different input waveforms.



Differentiating Effects upon Different Waveforms

Although the circuit provides no amplification, for a square wave input, the peak output of the differentiator is twice that of the input signal. A positive pulse is produced for the positive leading edge and a negative pulse for the negative trailing edge.

With a sine-wave input the output remains a sine-wave as shown in part B of the illustration, the only differences being that the output sine-wave is of a smaller amplitude and is advanced in phase. The advance for a perfect differentiator is 90 degrees, but 89 degrees is not uncommon.

The sawtooth, shown in part C of the illustration is converted into a low amplitude square wave. Part D illustrates effect of a differentiator upon the application of a complex waveform.

Since the inductor has distributed (turns) capacitance across it, undesired resonant responses may occur in L-R circuits containing large values of inductance; therefore, the use of these networks is usually limited to high frequency applications.

FAILURE ANALYSIS.

No Output. Since only two components are involved, it is evident that only an open circuit at the input, or a short circuit at the output, could produce a no-output condition.

Low or Distorted Output. Only a change in component values or associated stray capacitance, inductance, and resistance values could change the time constant and waveshapes. Distorted output is usually caused by improper input signals. When checking the waveform at the differentiator, the effect of the shunt resistance or capacitance produced by the test instrument input should be considered. When distortion is discovered in the following tube circuits, it is probably caused by improper action in these circuits. A direct check of the output as compared with the input of the differentiator using a high-impedance oscilloscope, will indicate whether the circuit is performing properly. A shorted resistor or an open coil would cause the output to be a duplicate of the input (no differentiation taking place).

R-C INTEGRATOR.

APPLICATION.

The R-C integrator is used as a waveshaping network in radio, television, radar, and computers, as well as many other special electronic applications.

CHARACTERISTICS.

Input waveshape distorted (non-sinusoidal).

Produces a distortion of the input waveform.

Provides a wider range of time constants than an R-L integrator.

Has a long time constant.

Output is taken from across the capacitor.

Has the configuration of a low-pass filter.

No amplification is produced.

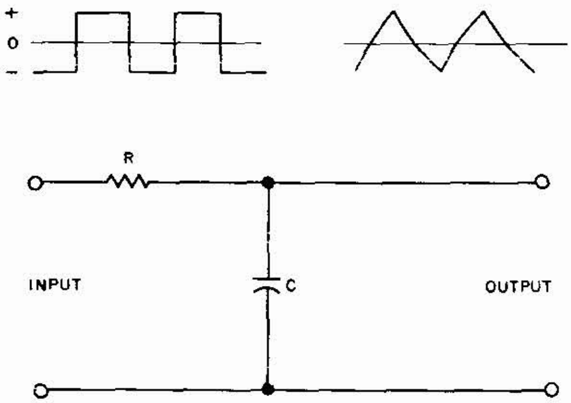
CIRCUIT ANALYSIS.

General. The R-C integrator circuit works in almost exact opposition to the R-C differentiator. It has a long time constant, and the output is taken from across the capacitor. The time constant of the integrator circuit should be 5 times (or more) the period of one alternation of the input waveform, for the circuit to electronically perform the mathematical operation of integration. As in the case of the differentiator, this action in practice is approximate, but the approximation can be made very close.

The higher the resistance in the R-C integrator, the more closely the output voltage follows the ideal integrator waveform. However, the higher this resistance, the smaller the output voltage. Conversely, decreasing the resistance in the R-C integrator circuit, results in a shorter time constant and a higher output voltage. However, as the resistance is reduced in value, the output voltage departs from the ideal integrator waveform. In fact if the resistance, (and time constant) of the R-C circuit is sufficiently reduced, a point will be reached where the circuit no longer acts as an integrator.

The output of an integrator is in the form of a voltage that represents the average energy content of the input signal. For example, if the input is a steady d-c voltage, the same voltage will appear at the output, but, if the input is in the form of a series of narrow, widely separated pulses, the output voltage will be only a fraction of the input pulse value.

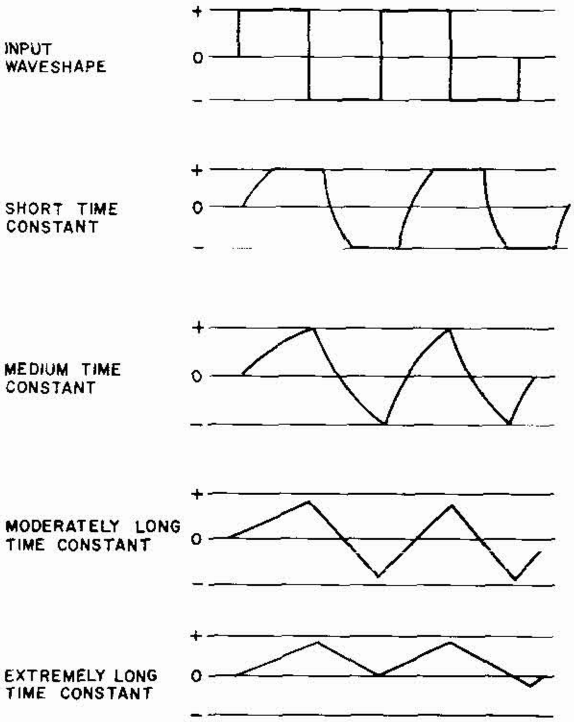
Circuit Operation. A schematic of a basic R-C integrator is shown in the accompanying illustration.



Basic R-C Integrator Circuit

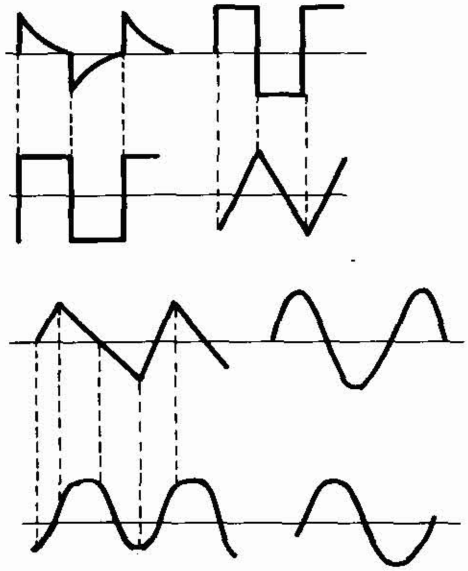
As the square wave voltage applied to the input of the circuit goes positive, the capacitor charges exponentially at a rate determined by the time constant of the circuit. This time constant is calculated by multiplying the value of the resistor by the value of the capacitor (T=RC). For instance, a circuit containing a 100K resistor and a 50 picofarad capacitor would have a time constant of 5 microseconds, and if the value of the capacitor was increased ten times to 500 picofarads, the time constant would be ten times longer or 50 microseconds. The rise in voltage across the capacitor occurs as the voltage across R decreases from its maximum value. The voltage drop across the capacitor is always the difference between the input voltage and the voltage drop across the resistor. The rise in voltage across the capacitor occurs only for the duration of the applied square wave pulse. When the applied voltage drops from its maximum value, the capacitor discharges exponentially at the same rate that it charged, due to the time constant of the circuit. This gradual decrease in voltage across C effectively causes a negative pulse across R. If a square wave is applied to an R-C integrator circuit, a non-symmetrical saw-tooth waveform is produced. The principle of integration is used in saw-tooth generators to produce the linear rise in voltage by using a long time constant circuit, and to use only the straight portion of the exponential charge waveform for linearity.

The accompanying waveform illustration shows the integrating effect of various time constants on a square wave.



Effects of Changing Time Constant

As can be seen from the waveforms in the illustration, a short time constant integrator does not change the input waveform very much except to distort the high frequency portions of the waveform (leading and trailing edges), and the low frequency (flat) portion is practically unchanged. As the time constant is changed to a medium value time constant, the waveshape changes to that of a rounded-off triangle (sweep waveform). With a moderately long time constant, the triangular waveform is equally distributed about the central zero axis and the slopes are practically straight. When the time constant is made extremely long, it consists of somewhat elongated (stretched) sawtoothed waveforms of reduced amplitude which gradually approach the zero axis, and eventually, after a number of time constants, becomes symmetrically aligned around the center (zero) axis. A short time constant would be considered one which amounted to only one tenth of the pulse duration time. A medium time constant would be of the order of half the pulse duration, while a moderately long time constant would be approximately equivalent to the full pulse width. A long or extremely long time constant would be considered to amount to two or three pulse widths or longer.



***Integrating* Effect of Different Waveforms**

The accompanying illustration shows different types of inputs and their respective output for an R-C integrator circuit. The amplitudes of the waveshapes are different and bear no relation to each other as shown in the illustration. When a peaked waveform is applied to an R-C integrator circuit, the resultant output will be a square waveform. Applying a square wave to the input of an integrator circuit produces an output waveform of triangular shape. The integration of a triangular wave results in a parabolic output wave. Integrating a sine wave by an R-C circuit produces another sine wave with a different amplitude and phase, but with the same sinusoidal waveshape (usually considered to be a cosine waveform).

FAILURE ANALYSIS.

No Output. Since only two components are involved, it is evident that only an open circuit at the input, or a short circuit at the output, could produce a no-output condition (open resistor or shorted capacitor). Both of these items could be checked for with an ohmmeter. If the resistor is open the meter will indicate infinity, and if the capacitor is shorted the meter will read zero ohms.

Distorted Output. Only a change in component values, or associated component values, could change the time constant and waveshapes. Distorted output is usually caused by improper input signals. When distortion is discovered in the following tube or transistor circuits, it is probably caused by improper action in these circuits. A direct check of the output as compared with the input to the integrator using a high-impedance oscilloscope, will indicate whether the circuit is performing properly. A shorted resistor or an open capacitor would cause the output to be a duplicate of the input (no integration taking place). The value of the resistor can be checked with an ohmmeter. While the capacitor can also be checked for a short with the ohmmeter, it is better practice to use an in-circuit capacitance checker, and also to check the capacitor for both proper value and leakage.

R-L INTEGRATOR.

APPLICATION.

The R-L integrator is used as a waveshaping network in various types of electronic equipments such as radio, radar, television and in other special electronic application. It is also used as an analog in performing the mathematical function of integration in computers.

CHARACTERISTICS.

Produces distortion of the input waveshape.

Has a long time constant.

Output is taken across the resistor.

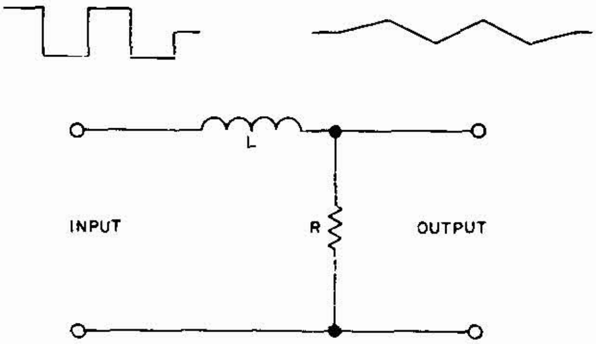
Has the configuration of a low pass filter.

Output is in the form of a voltage that represents the average energy content of the input waveform.

CIRCUIT ANALYSIS.

General. An integrating circuit is a circuit whose output is substantially the time integral of its input waveform. The R-L integrator circuit works in almost exact opposition to the R-L differentiator. It has a long time constant and the output is taken from across the resistor. If the time constant of the integrator circuit is 5 times (or more) the period of one alternation of the input waveform the circuit will electronically perform the mathematical operation of integration. This action is approximate in practice, but the approximation can be made very accurate. Since inductor action is the heart of the operation of the R-L integrator a brief review of inductor action follows. The property of inductance is such as to oppose a change in current. This opposition (impedance) exerted by an inductor exists because a counter emf is produced across the inductor by the change in the magnetic field of the inductor. When a constant voltage is applied across an inductor, current flow does not rise to a maximum value immediately. Rather, it is initially zero and increases at an exponential rate, as the inductor becomes charged and the counter e.m.f. decreases. Likewise, when the applied voltage is removed, circuit current does not fall to zero immediately, but decreases at an exponential rate as the energy stored in the magnetic field of the inductor is discharged. In the R-L integrator circuit the longer the time constant, the more closely the output waveform follows the ideal integrator waveform. However, the longer the time constant, the smaller is the output voltage.

Circuit Operation. The accompanying schematic diagram illustrates a typical R-L integrator.

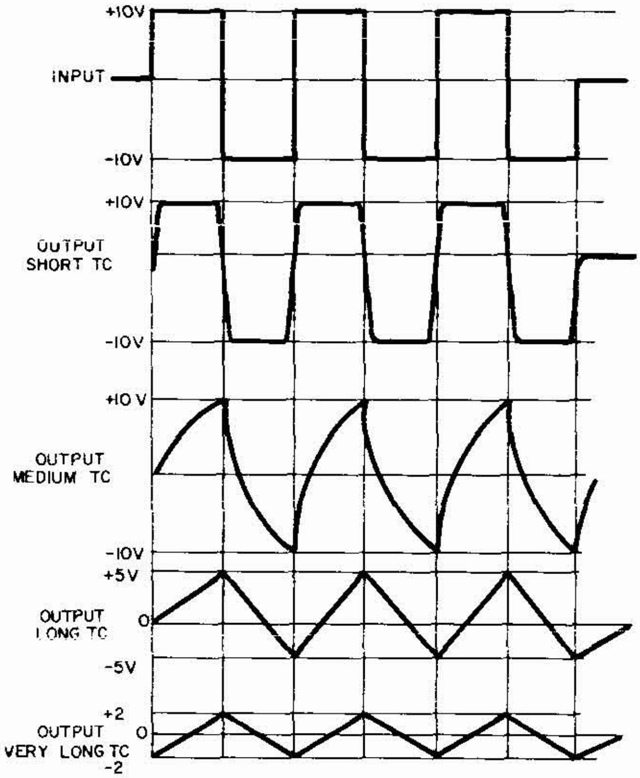


Typical R-L Integrator

This R-L integrator consists of a series R-L circuit with the output taken across the resistor. The charge and discharge time of the inductor (the time constant) is determined by the values of inductance and resistance in the circuit using the formula TC=L/R. Thus an integrator circuit consisting of a .1 henry inductor and a 10,000-ohm resistor has a time constant of 10 microseconds.

When a square wave is applied to the input of the integrator circuit the inductor begins to charge. The impedance, caused by counter e.m.f. generated by the expanding magnetic field is initially maximum, but decreases exponentially at a rate determined by the values of L and R as the magnetic field of the inductor approaches its limit. Circuit current, therefore, begins at zero and increases exponentially as the circuit impedance decreases. It is evident that the IR drop (voltage) across the output resistor begins at zero and increases as the inductor becomes charged. If the time constant is very long the increase in output voltage is nearly linear, but the peak of the output waveform attains only a fraction of the amplitude of the input signal, since the inductor attains only a slight charge during the period when voltage is applied to the input. When the input signal falls back to its reference level, the inductor discharges exponentially at the same rate as it charged. The decreasing current induced in the circuit by the collapsing field of the inductor results in a steadily decreasing voltage developed across output resistor R. The output of an integrator circuit with a long time constant (2 or more pulse widths), therefore, is a triangular waveform, which slopes up (positive) during the period when a positive pulse is applied, and slopes down (negative) during the period when the input is at its reference level. Conversely, when a negative going pulse is applied to the R-L integrator the output voltage goes negative and when the input voltage returns to its reference level the output voltage goes positive.

The following waveforms represent the integrating effects of various time constant integrator circuits on a square wave input.



Effects of Various Time Constants On A Square Wave

As can be seen from the waveforms in the illustration, a short time constant integrator has little effect on the output waveform, only the high frequency components (leading and trailing edges) are attenuated. As the time constant is increased the output begins to resemble a sweep waveform. A further increase in time constant results in a more linear rise and fall of the output waveform. Notice that the output waveform of the long and very long time constant integrator does not reach the peak amplitude of the input waveform, but is always a much lower value.

FAILURE ANALYSIS.

No Output. Since there are only two components in the R-L integrator, a no-output condition could only be caused by an open inductor, a shorted resistor, or by no signal input. Both the inductor and the resistor can easily be checked for the above mentioned conditions with an ohmmeter. Presence of the input signal can be determined by observing the waveform present at the input to the integrator with an oscilloscope.

Distorted Output. Generally speaking, an integrator circuit will either function as designed or not at all. However, it is possible for either the inductor or the resistor to change value. This would change the integrator time constant, and the output waveshape would be altered. The resistor may be checked for proper value with an ohmmeter, and the inductor can be checked for proper value with an impedance bridge. It is also possible for the inductor to become shorted or the resistor to become open. This would result in the output being a duplicate of the input (no integration taking place). The components can be checked as explained previously. The most common cause of distorted output is probably distorted input. The quality of the input signal can be easily determined by viewing the waveform present at the integrator input with an oscilloscope.

SATURABLE-CORE REACTOR PEAKING CIRCUIT.

APPLICATION.

The saturable-core reactor peaking circuit is used to produce a peaked pulse of voltage from a sine wave input.

CHARACTERISTICS.

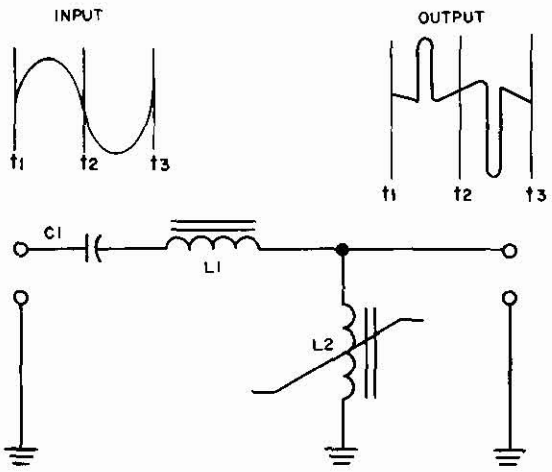
Utilizes a saturable reactor.
Output voltage pulses are in phase with the input signal.
Usually operated near resonance.
Output pulse width is determined by the circuit Q.

CIRCUIT ANALYSIS.

General. The saturable-core reactor peaking circuit produces sharp voltage pulses from a sine wave input signal by utilizing the properties of a saturable reactor. A saturable-core reactor is a type of inductor in which a relatively low value of current produces magnetic saturation of the core.

Magnetic saturation of an inductor core can be defined as the point where a further increase in current flow through the inductor windings does not result in any further increase in magnetic field. The property of inductance is such as to oppose a change in current. This opposition (impedance) exerted by an inductor exists because a counter e.m.f. is produced across the inductor, which opposes the applied voltage. If the core of a inductor were to become saturated, the counter e.m.f. would drop to a low value, and its opposition to current flow (impedance) would also drop to a low value. It is this ability to change impedance that enables the saturable-core reactor peaking circuit to produce a pulse output from a sinewave input.

Circuit Operation. The accompanying schematic diagram illustrates a typical saturable-core reactor peaking circuit.



Saturable-Core Reactor Peaking Circuit

The circuit illustrated above consists simply of conventional capacitor C1, conventional inductor L1, and saturable core reactor L2. Component values are chosen so that the circuit appears slightly capacitive when L2 is saturated and slightly inductive when L2 is unsaturated (the inductance of L2 decreases when L2 becomes saturated). To illustrate the capacitive-inductive relationships when L2 is saturated or unsaturated, assume for the sake of illustration that C1 has a capacitive reactance of 100 ohms at the operating frequency and that L1 has an inductive reactance of 75 ohms at the operating frequency. Assume further that L2 also has an inductive reactance of 40 ohms when unsaturated and 10 ohms when saturated. The reactance of both C1 and L1 remain constant. It can be seen that during the period when L2 is unsaturated there is a total of 115 ohms of inductive reactance and 100 ohms of capacitive reactance in the circuit. The circuit, therefore, appears inductive since the effect of L1 predominates. Likewise, when L2 is saturated there is 100 ohms of capacitive reactance but only 85 ohms of inductive reactance, and the circuit now appears capacitive.

When a sine wave is applied to the saturable-core reactor peaking circuit, L2 becomes saturated by the relatively high current flowing through it, and the voltage across L2 is very low, since the inductance of L2 is also very low at this time. Since the circuit is slightly capacitive during the saturation of L2, the current in the circuit leads the applied voltage by almost 90°, and the output voltage is approximately 180 degrees out of phase with the applied voltage, since the voltage across L2 also leads the current by nearly 90°. This output voltage is very low in amplitude, since L2 offers little impedance while in the saturated state. Inductor L2 becomes unsaturated when the input voltage is at a peak, since at this time circuit current is at a minimum due to the 90° phase shift. At this time (when L2 is unsaturated) the inductance of L2 becomes high. This makes the circuit highly inductive and causes the circuit current to lag the applied voltage by almost 90°. However, the voltage across L1 (the output) leads the circuit current by almost 90°, since voltage leads current across an inductor and is, therefore, in phase with the input. This condition persists for only a short period of time until the circuit current increases and becomes sufficient to saturate L2. During this short period of time a large amplitude pulse which is inphase with the input is produced. The duration of this pulse coincides with the duration of the unsaturated condition of L2 and is determined mainly by the circuit Q. Thus, a large amplitude positive pulse is produced when the applied sine wave passes through its positive peak, and a large amplitude negative pulse is produced when the applied sine wave passes through its negative peak. Since L2 is saturated during most of the input cycle, the output is extremely low except for the short time during the peaks of voltage when L2 is in an unsaturated condition.

FAILURE ANALYSIS.

No Output. A no-output condition could result if any component in the saturable reactor peaking circuit became shorted or open. Inductors L1 and L2 can easily be checked by measuring the resistance of the windings and checking for a short or leakage to ground with an ohmmeter. Capacitor C1 can be checked with an in-circuit capacitor checker. Do not overlook the possibility that a no-output condition is the result of no-input. This can easily be checked by observing if the waveform is present at the circuit input with an oscilloscope.

Low Output. Generally speaking, since there are few components involved, the saturable-core reactor peaking circuit will either function as designed or not at all. However, a low-output condition could result from a partially shorted component or from excessive leakage to ground of the windings of L1 or L2, or from a low amplitude input. Resistance checks of the inductor windings and resistance checks to ground, with the bottom of L2 disconnected, should reveal whether or not a partially shorted component or leakage to ground is the cause of low output. The amplitude of the input signal can easily be checked by observing the waveform present at the input with an oscilloscope.

Distorted Output. Since the duration of the output pulse is determined mainly by the Q of the circuit, a change in circuit value could alter the Q of the circuit and thus alter the output waveshape. Checks for excessive leakage to ground should be made using an ohmmeter, since leakage to ground would affect the circuit Q. C1, L1 and L2 can be checked for proper value with an impedance bridge.

SEMICONDUCTOR PULSE SHAPER.

APPLICATION.

The semiconductor pulse shaper is used in computer, control, and communication equipment to reshape a pulse which has suffered deterioration of its waveshape after passing through a chain of gates. It is also used in conjunction with a multivibrator to form a 1 μ sec. pulse with sharp leading and trailing edges.

CHARACTERISTICS.

Reshapes pulses into pulses with sharp leading and trailing edges.

Utilizes two transistors connected in the common-emitter configuration.

Requires three power supply voltages.

Output pulse width is constant and is determined by circuit components.

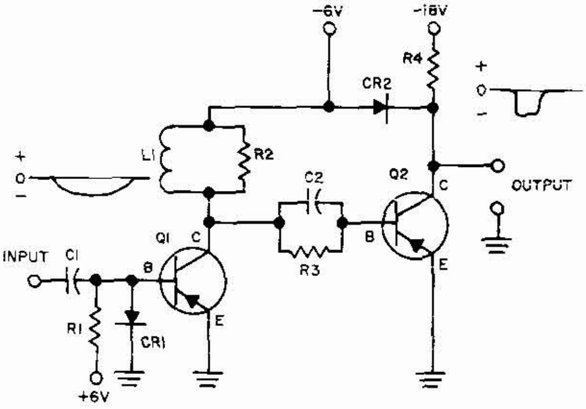
Capable of driving several loads.

CIRCUIT ANALYSIS.

General. The semiconductor pulse shaping circuit consists of two common-emitter amplifiers. The first stage, which employs an R-L collector load, performs the primary shaping function and controls the output pulse width. The second stage, an overdriven amplifier, serves as a buffer power amplifier, and in addition squares off the trailing edge of the output pulse.

The output pulse width is primarily determined by the values of the inductive load of the first stage and the input capacitor, but is also affected by transistor characteristics, as well as changes in the power supply voltage. In most instances circuit values are chosen which produce an output pulse width of 1 microsecond.

Circuit Operation. The accompanying schematic diagram illustrates a typical semiconductor pulse shaper using the common-emitter configuration.



Semiconductor Pulse Shaper

Capacitor C1 couples the input pulse to the base of transistor Q1. Resistor R1 and diode CR1 form a voltage divider between ground and the +6 volt bias supply to apply reverse bias to the base of transistor Q1. Inductor L1 and resistor R2 form the collector load for transistor Q1, and capacitor C2 together with resistor R3 forms an interstage coupling network from the collector of Q1 to the base of Q2. Transistor Q2, which is operated as an overdriven amplifier, serves as the output stage, with resistor R4 as its collector load, and diode CR2 limiting the output to the level of the -6 volt power supply.

In the quiescent state (no signal input) transistor Q1 is reverse biased by the positive voltage at the junction of voltage divider R1-CR1. The collector of Q1 is at approximately -6 volts since Q1 forward collector current is cut off, and transistor Q2 is heavily forward biased by the negative collector voltage of Q1 direct-coupled through R3. With Q2 conducting heavily, the output voltage is very close to ground potential. When a negative pulse is applied to the pulse shaper, voltage divider diode CR1 is reverse biased and transistor Q1 is driven into conduction by the charging current flowing through the emitter-base junction of Q1 and into capacitor C1. The rapid rise in charging current through the emitter-base junction of Q1 rapidly drives Q1 into saturation, and the voltage on the collector of Q1 rises sharply to ground potential. This rapid positive swing in collector voltage on Q1 is coupled through R3 and C2 to the base of output transistor Q2, and Q2 is rapidly cutoff. The collector voltage of Q2 (the output voltage) which was previously held at ground potential due to the heavy conduction of Q2 now rapidly falls to the -6 volt supply level. This is the beginning of the output pulse. The amplitude of the output pulse is maintained at a constant -6 volts by the action of limiting diode CR2. Transistor Q1 is maintained in a saturated state by the charging current of C1 flowing through the emitter-base junction of Q1. This current decreases as C1 becomes charged, but remains sufficient to keep Q1 saturated for the duration of the output pulse. During the period when Q1 is saturated, collector current is limited by the impedance of the load (L1 and R2). Initially, the impedance of L1 is high, but it decreases as L1 becomes charged and collector current increases. Consequently, during the period when Q1 is in saturation, collector voltage on Q1 remains constant and output transistor Q2 remains cut off. Hence, the output voltage remains at -6 volts. When the desired output pulse width is completed, the impedance of L1 is so low that the base drive caused by the charging current of C1 is insufficient to maintain collector current at the previous level. (Base drive decreases as C1 charges). Collector current then decreases rapidly and Q1 collector voltage quickly falls to -6 volts, which drives output transistor Q2 into saturation. The output voltage rises sharply to ground potential as the conduction of Q2 increases. The rapid transition of Q2 from cutoff to saturation is aided by the discharge through the emitter-base junction of Q1, of the energy stored in L1. The term "cutoff" has been used loosely in the preceding paragraphs. Actually the transistors are not cut off in the sense that a vacuum tube can be cut off, since there is always some reverse leakage current flowing, but the magnitude of this current is insignificant. The values of C1 and L1 are the determining factors affecting output pulse width, since the output pulse is completed when C1 and L1 become fully charged and cause the collector current of Q1 to begin decreasing.

FAILURE ANALYSIS.

General. When making voltage checks, use a vacuum tube voltmeter to avoid the low values of multiplier resistance employed on the low voltage ranges of the standard 20,000 ohms-per-volt meter. Be careful also to observe proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junctions will cause a false low resistance reading.

No Output. A no-output condition could result from failure of either transistor or failure of one of the power supplies. Semiconductor circuits are generally miniaturized printed circuits. Circuits of this type are subject to shorts caused by a small drop of solder, or any conductive object that may fall across printed circuit leads, or these leads may become open by a hairline crack in the printed board. Plug-in type contacts, often employed in printed circuit boards, sometimes fail to make contact due to dirty or bent contacts. It is often wise to visually check the printed circuit board for evidence of any of the above conditions before attempting to trouble-shoot the circuit. Power supply voltages should be checked with a vacuum-tube-voltmeter, and adjusted or repaired if necessary. It should be noted that deterioration with age causing lack of gain may result under high temperature conditions. Unlike vacuum tubes, however, transistors have operated for years without noticeable deterioration under proper operating conditions. If the transistor is not at fault, a defective circuit component is likely the cause of no output. Voltage checks of transistors elements with a vacuum tube voltmeter, or resistance checks with the circuit deenergized, should indicate the component at fault. Resistors R3 or R4 could cause a no-output condition if they failed, as could diode CR1 if it became shorted. Failure of other circuit components could possibly cause a no-output condition to exist, but are much more likely to cause distortion of the output waveshape. This condition will be discussed in detail in the following paragraph. Do no overlook the possibility that a no-output condition is the result of no input signal reaching the pulse shaper. The existance of this condition can readily be determined by observing the waveform present at the input to capacitor C1 with an oscilloscope.

Distorted Output. The term distorted output is used in the following paragraph to describe any output condition other than the proper output with respect to pulse width, pulse amplitude, and pulse rise and fall time since a circuit defect usually causes more than one of these symptoms of improper output to appear. Defective transistors and improper power supply voltages are often the cause of a distorted output. The power supply voltages should be checked and adjusted if necessary, they should be within 10% of their nominal values. If the power supply voltages are correct and the transistors are good, a defective circuit component is the next most likely cause of improper output. A significant change in the value of any component could alter the output waveshape. Since the value of L1 and C1 determine the pulse width a change in the value of these components would, naturally, affect the output pulse width. L1 and C1 can be checked for proper value on an inductance-capacitance bridge. Resistors R1 and R2 also affect pulse width but to a lesser degree than C1 and L1. Diode CR2 limits the amplitude of the output pulse to -6 volts. If CR2 opened, the amplitude of the output pulse would increase. The input pulse must be of the correct polarity, and have sufficient amplitude and duration to properly trigger the pulse shaper, if a good output pulse is to be generated. The condition of the input pulse may be checked by observing the waveform present at the input to capacitor C1 with an oscilloscope.