Electronic circuits are sometimes as different as night and day. One type of circuit might require 1000 volts to operate while another circuit may only need 5 volts to operate. Just as different operating voltages are sometimes required, so are different waveforms. During this lesson we will discuss how RC circuits develop various waveforms.

During this lesson, you will see what happens when a square wave signal is applied to a resistor and capacitor in a series circuit. After a brief review of capacitor operation, you will learn how to determine the charge and discharge time for a capacitor. You will also learn how to obtain many different kinds of output waveshapes from a simple RC circuit; waveshapes which will be square, triangular, spiked, or rounded in nature. Thus, this lesson should serve to increase your knowledge about the capacitor, while also introducing you to some fascinating and useful electronic waveshapes.

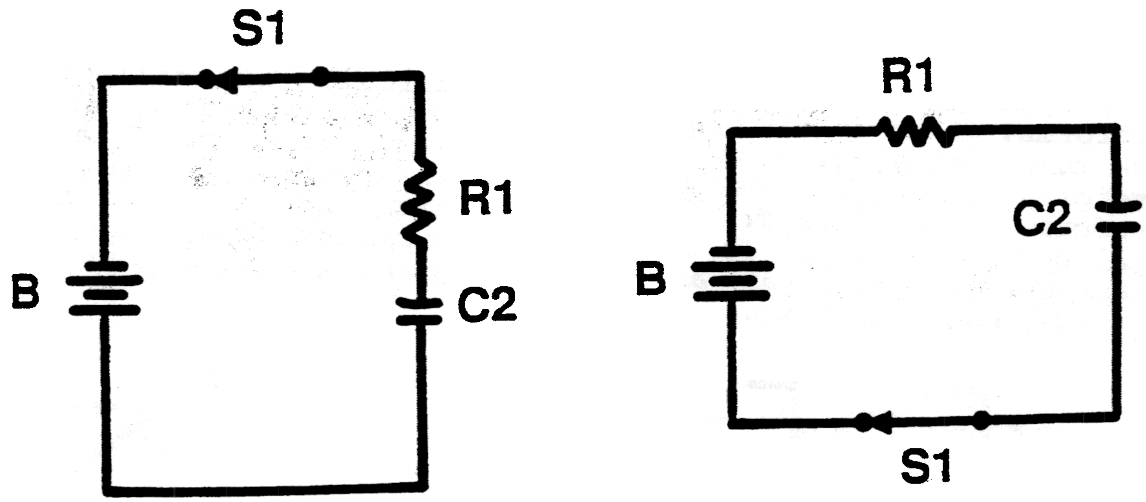


FIGURE 3

A RC circuit is made by connecting a resistor and a capacitor in series. This view shows two (2) types of RC circuits. Notice that both circuits have a resistor and a capacitor connected in series.

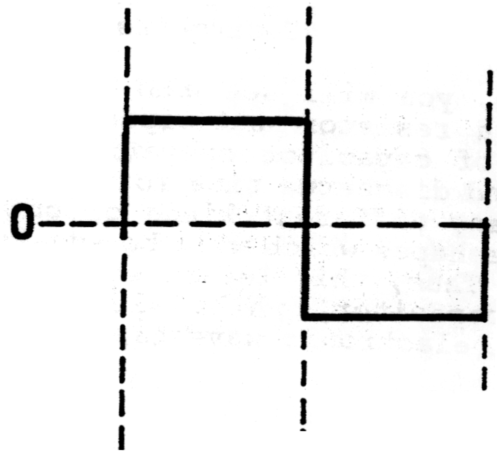


FIGURE 4

The waveform produced by some RC circuits are called transient waveforms. A transient waveform is a waveform that constantly changes from one steady state to another. A sine wave is not a transient waveform. One type of transient waveform is shown in this view. The waveform is positive for a period of time and less positive for an equal period of time. It is constantly changing from a positive level to a less positive level, and this allows the waveform to be classified as a transient waveform.

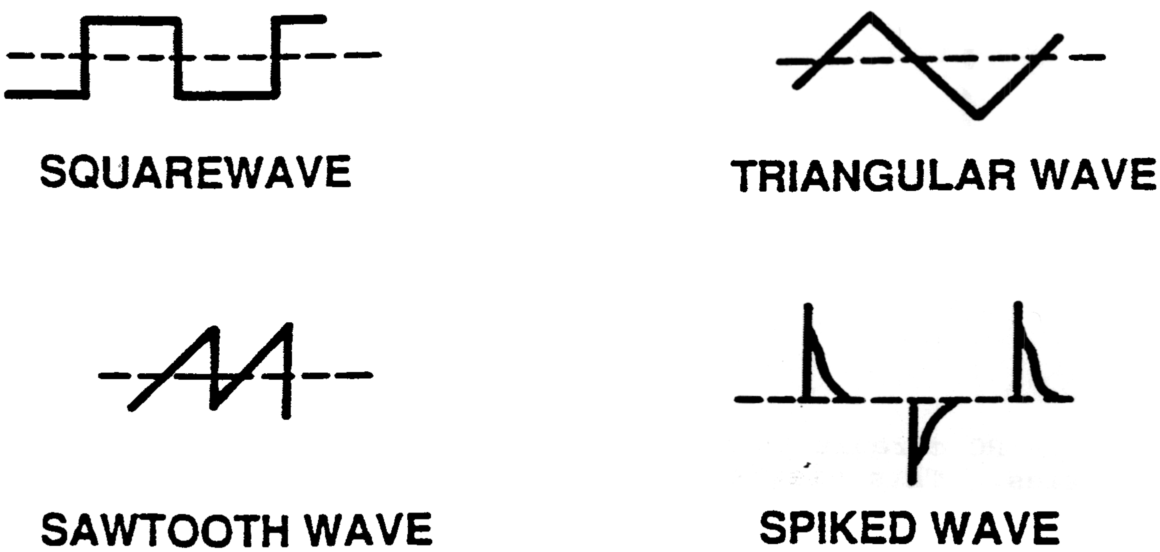


FIGURE 5

The square wave, triangular wave, sawtooth wave, and spiked wave, all of which are shown in this view, are four (4) types of transient waveforms. These waveforms are constantly changing from a positive going voltage to a negative going voltage.

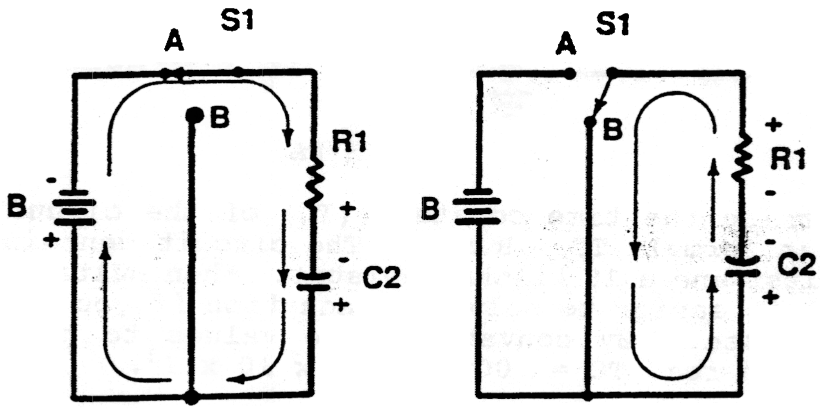


FIGURE 6

RC circuits have the capability of producing transient waveforms. The production of transient waveforms can be accomplished by the charging of a capacitor through a resistor.

The RC circuit in this view is connected to a battery. A transient input voltage can be simulated by using a battery and a switch.

If the switch is placed in Position A, the capacitor will charge to the applied voltage. The rate, or how fast the capacitor charges, is dependent on the values of the resistor and capacitor or time constant (TC).

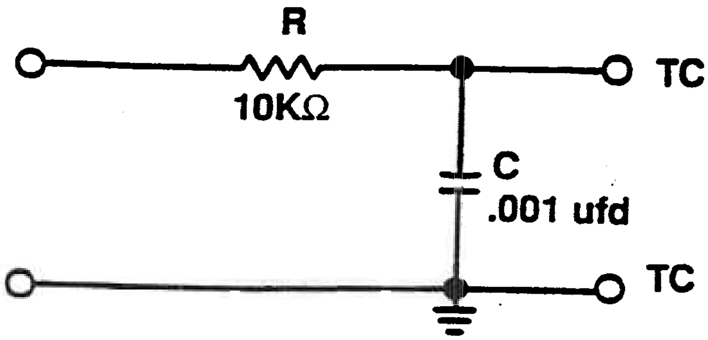
If the switch is placed in Position B, the capacitor will discharge in the opposite direction that it charged in. The rate of capacitor discharge is also dependent upon the value of the resistor and capacitor.

TIME CONSTANT = RESISTOR x CAPACITOR

$$TC = R \times C$$

FIGURE 7

If the values of the resistor and capacitor are known, the charge time of a capacitor can be calculated. By multiplying the value of the resistor times the value of the capacitor, the time constant (TC) of the circuit may be obtained. One (1) time constant (TC) equals the amount of time required for a capacitor to charge to approximately 63% of the applied voltage the capacitor has charged to. By using the formula TC = R x C, the time constant (TC) of a circuit can be calculated. With R given in ohms and C in farads, the time constant will be in seconds.



$$
\begin{aligned}
TC &= RC \\
&= .001 \times 10^{-6} \times 10 \times 10^{3} \\
&= .01 \times 10^{-3} \\
&= 010. \times 10^{-6} \\
&= 10 \times 10^{-6} \\
&= 10 \text{ usec}
\end{aligned}
$$

FIGURE 8A

To determine the time constant (TC) of the circuit shown in this view, use the formula TC = R x C. The circuit contains a .001 microfarad capacitor and a 10 kilohm resistor. When multiplying values such as these, it is easier to solve the equation if you convert the values to powers of ten. By converting the values to powers of ten, the equation should read TC = .001 x 10^{-6} x 10 x 1^{3}.

Multiply .001 x 10 and 10^{-6} x 10^{3}. The resulting equation should read TC = .01 x 10^{-3}.

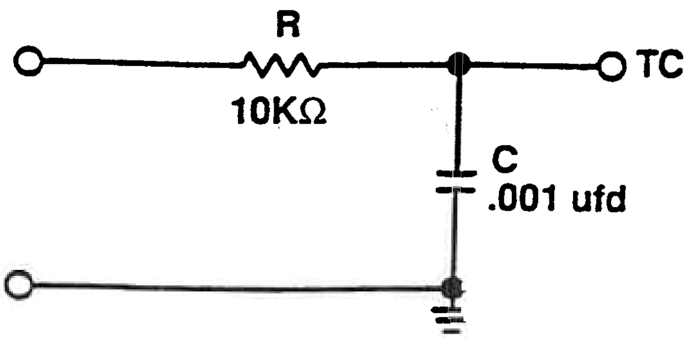


FIGURE 8B

.01 x 10^{-3} equals .01 milliseconds. Instead of expressing the answer in milliseconds, it is practical to express the answer in microseconds. In order to change the answer to microseconds, move the decimal point three (3) places to the right. The equation should then read 10 x 10^{-6} or 10 microseconds.

The capacitor in this circuit will charge to approximately 63% of the applied voltage in 10 usec. The capacitor will discharge approximately 63% of its charge in 10 usec.

C = .001 ufd	R = 5 K	TC = ________
C = .001 ufd	R = 10 K	TC = ________
C = .1 ufd	R = 1 K	TC = ________
C = .01 ufd	R = 20 K	TC = ________
C = .01 ufd	R = 10 K	TC = ________

FIGURE 9

Calculate the time constant for each of the RC values shown, in this view. Remember, the time constant is equal to the value of the resistor times the value of the capacitor. TC = R x C. With R given in ohms and C in farads, the time constant will be in seconds. However, the practical unit for the time constant is microseconds.

C = .001 ufd	R = 5 K	TC = 5 usec
C = .001 ufd	R = 10 K	TC = 10 usec
C = .1 ufd	R = 1 K	TC = 100 usec
C = .01 ufd	R = 20 K	TC = 200 usec
C = .01 ufd	R = 10 K	TC = 100 usec

FIGURE 10

The answers are shown in this view.

If you had any problems calculating the time constants shown in this view, ask your instructor for assistance.

1 Time Constant = 63%
4 Time Constant = 37%
5 Time Constants = 100% charge or discharge

FIGURE 11

One fact that has been mentioned is how long it takes a capacitor to charge or discharge completely. It was stated before that one (1) time constant is the time required for a capacitor to charge to approximately 63% of the applied voltage. Did you ever wonder what happened to the remaining 37%? Four (4) time constants are needed for the capacitor to charge to the remaining 37% of the applied voltage. This means that a capacitor will charge or discharge completely in five (5) time constants.

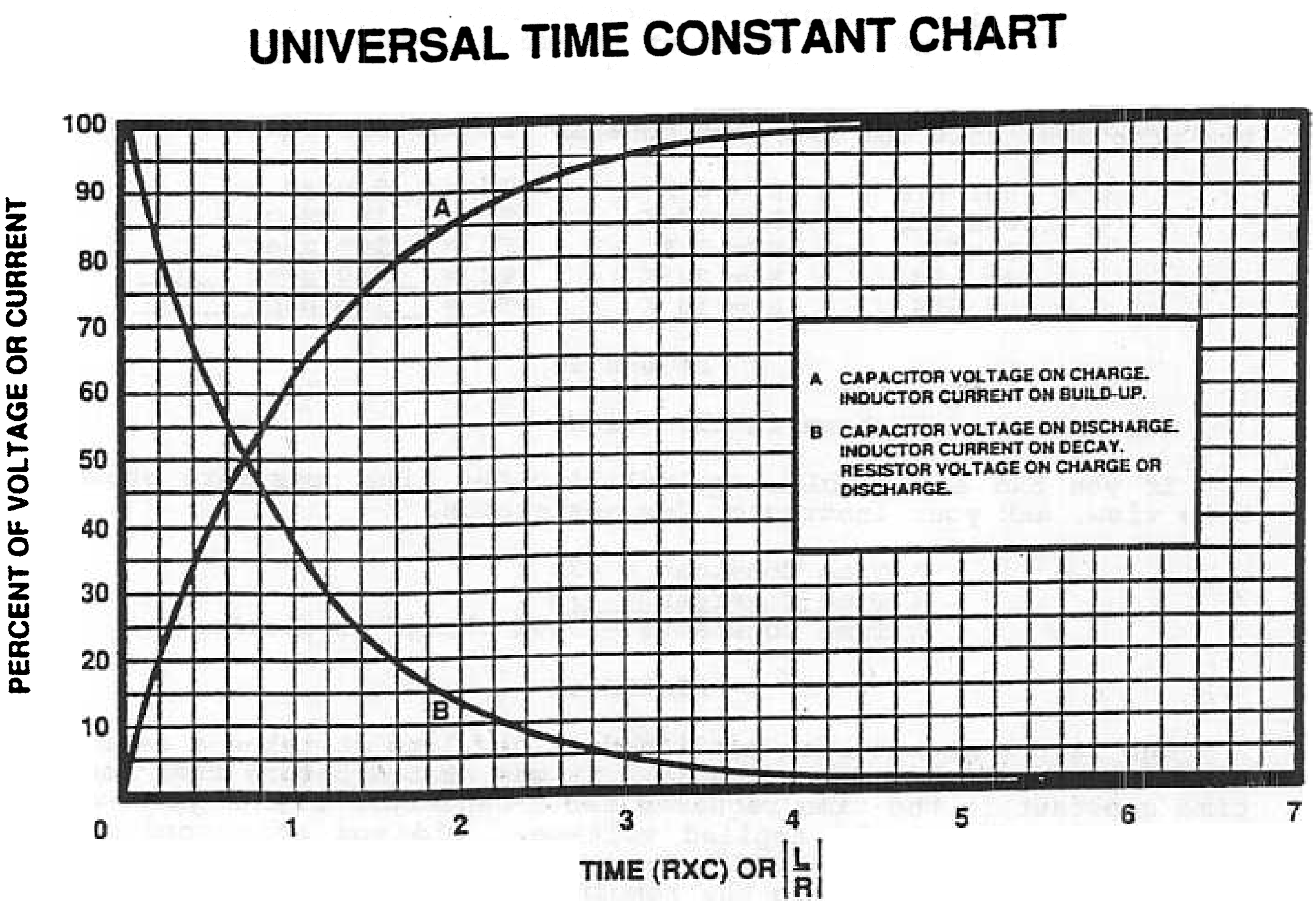


Figure 12

A <u>Universal Time Constant Chart</u> is shown in this view. A Universal Time Constant Chart is used when plotting the charge or discharge of a capacitor. These values apply for any capacitor.

The horizontal axis of the chart specifies the number of the time constant. There are seven (7) time constants on the chart, however, a capacitor requires five (5) time constants to charge or discharge.

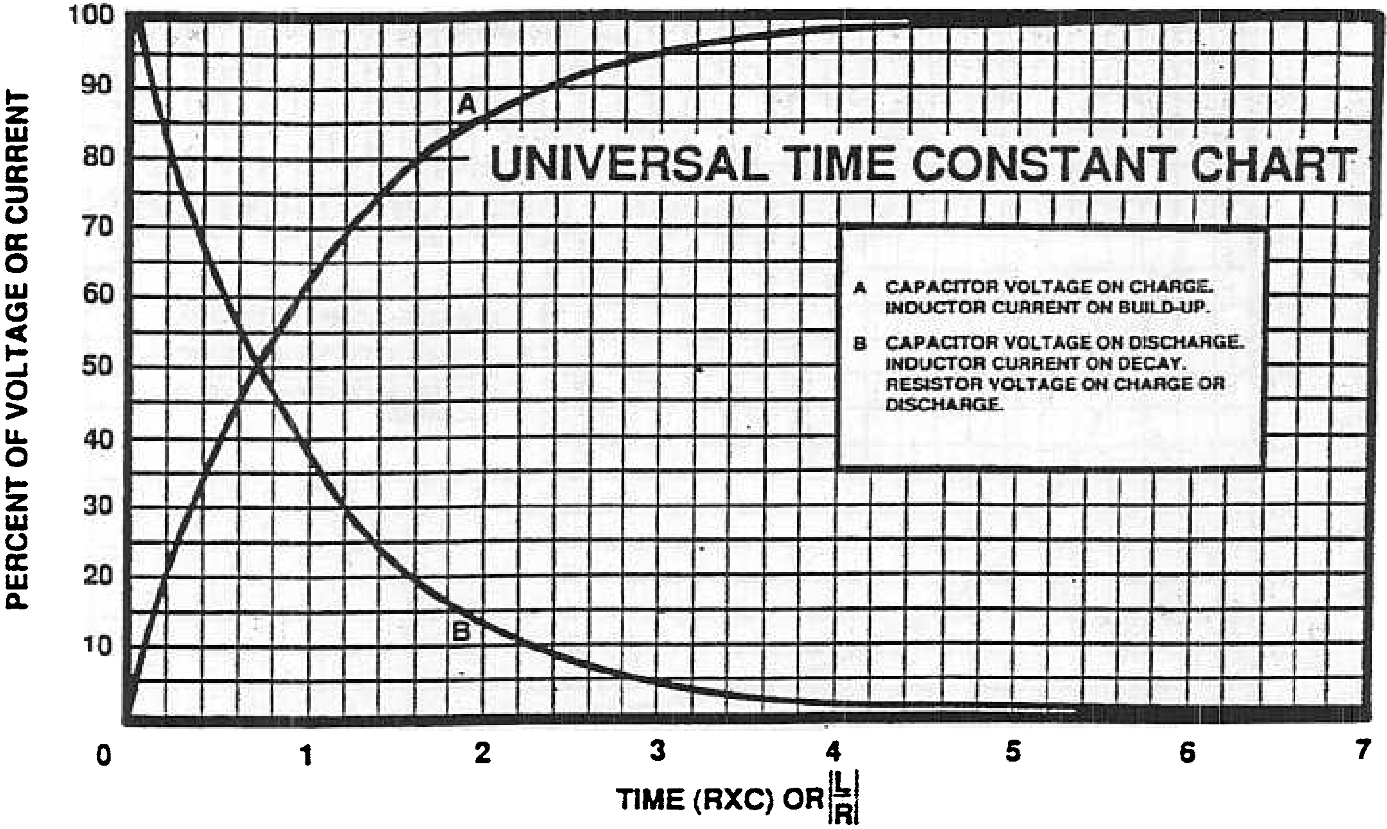


FIGURE 12A

The vertical axis indicates the percentage of applied voltage the capacitor is charged to at any point during it's charge or discharge.

Curve A is the charge curve of the capacitor, and curve B is the discharge curve.

For example, if we wanted to know the amount of voltage the capacitor has charged to in two (2) time constants, we would use the following procedures.

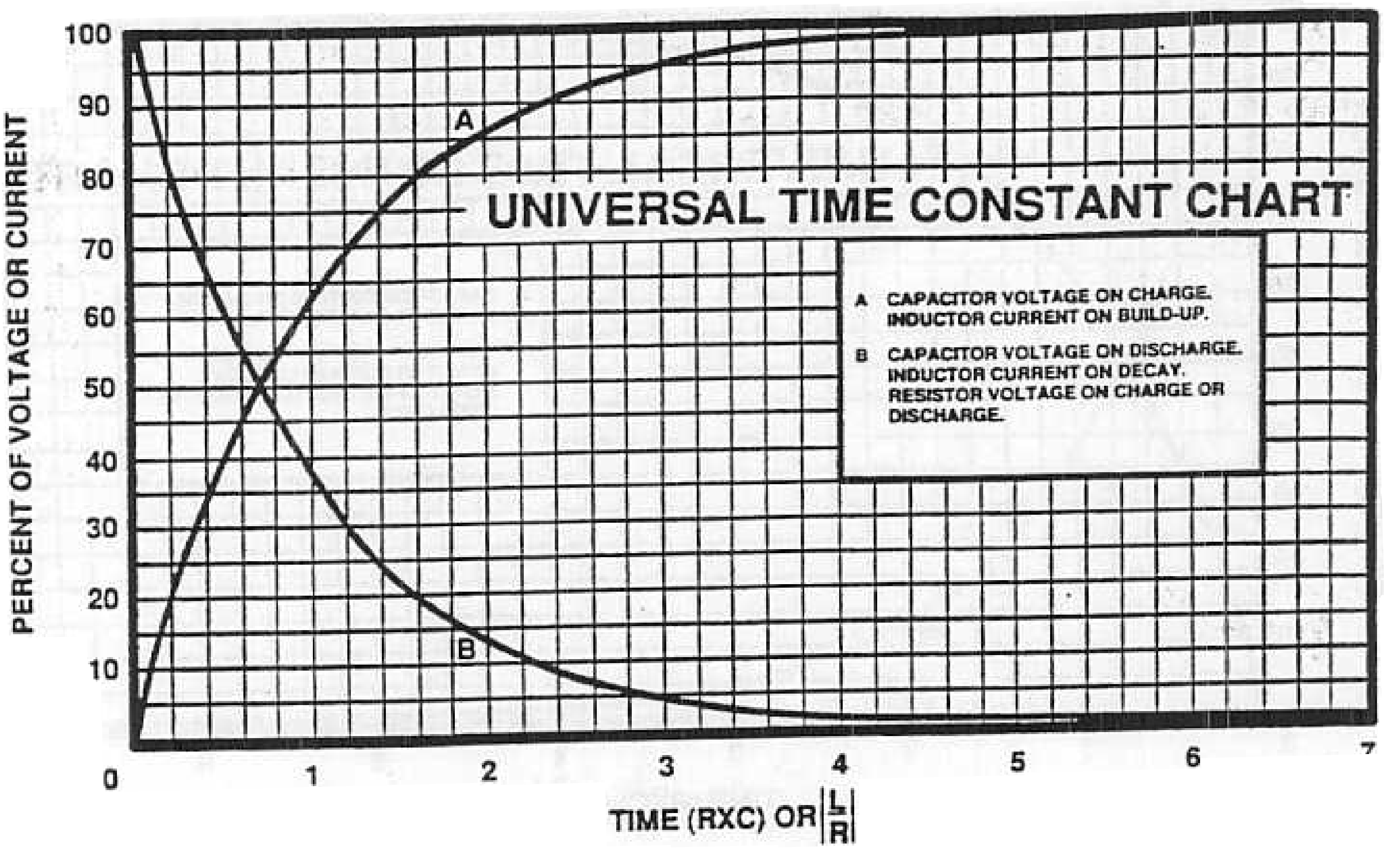


FIGURE 12B

Locate the second (#2) time constant on the horizontal axis.

Follow the second (#2) time constant line vertically until it intersects curve A,

Move horizontally to the left until you intersect the percentage of applied voltage axis.

This should tell you that after two (2) time constants the capacitor has charged to 87% of the applied voltage.

What percent of the applied voltage has the capacitor charged to after four (4) time constants?

Approximately 98%.

The student must complete JOB 1, on the PROBLEM SHEET.

Pulse Width = ½ (frequency)

PW = ½F

FIGURE 13

The pulse width of a signal applied to an RC circuit is just as important as the time constant of the circuit in determining what the output waveform will be. The capacitor in an RC circuit charges during the positive portion of the input signal, and discharges when the input signal goes less positive. If the pulse width of the input signal is short, the time constant of the RC circuit must be short to allow the capacitor time to charge. The pulse width of a symmetrical square wave can be calculated by using the formula Pulse Width = $\frac{1}{2F}$. This formula says multiply the input frequency times two (2) and divide the product into one (1). Do not use the pulse width formula on waveforms such as spikes and triangular waves because it does not apply to these types of waveforms.

50 KHz

$PW = \frac{1}{2F}$

$\frac{1}{2}(50 \times 10^3)$

$= 1/100 \times 10^3$

$.01 \times 10^{-3}$

$= 010.\ x$

$PW = 10$ usec

FIGURE 14A

The frequency of the square wave shown in this view is 50 KHZ. To determine the pulse width of the 50KHZ square wave, use the formula $PW = \frac{1}{2F}$. The first step in the formula should read $PW = \frac{1}{2}(50 \times 10^3)$. Notice that the frequency is expressed in powers of ten. Powers of ten are easier to work with when large numbers are being used.

Multiply tow (2) times fifty (50). The resulting equation should read $PW = 1/(100 \times 10^3)$.

Divide 100 into 1 and move the 10^3 above the line. Remember, when moving an exponent from denominator to numerator, the sign of the exponent changes. The resulting equation should read $PW = .01 \times 10^{-3}$.

50 KHz

$PW = \frac{1}{2F}$

$= \frac{1}{2}(50 \times 10^3)$

$= 1/100 \times 10^3$

$= .01 \times 10^{-3}$

$= 010.\ x$

$PW = 10$ usec

FIGURE 14B

Convert the equation so that the final answer is expressed in microseconds. To accomplish this, move the decimal point three (3) places to the right. This should make the final answer read 10 x 10^{-6}.

10 x 10^{-6} is equal to 10 usec since 10^{-6} is micro. This means that time for the pulse width is 10 usec.

1 KHZ	PW = ________
5 KHZ	PW = ________
10 KHZ	PW = ________
20 KHZ	PW = ________
50 KHZ	PW = ________

FIGURE 15 (SLIDE - EP25AL-S15)

Calculate the pulse width for each frequency shown in this view. Remember, the pulse width is equal to twice the frequency divided into one (1). $PW = \frac{1}{2F}$. The answers must be in microseconds (usec).

1 KHZ	PW = 500 usec
5 KHZ	PW = 100 usec
10 KHZ	PW = 50 usec
20 KHZ	PW = 25 usec
50 KHZ	PW = 10 usec

FIGURE 16 (SLIDE - EP25AL-S16)

The answers are shown in this view.

If you had any problems calculating the pulse width of the frequencies shown in this view, ask your instructor for assistance.

The student must complete JOB 2, on the PROBLEM SHEET.

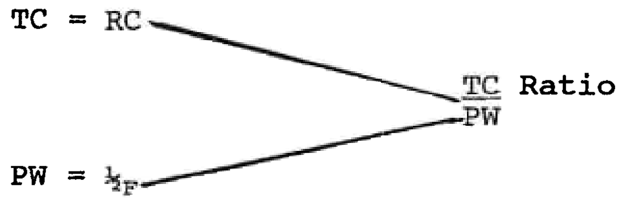


FIGURE 17

Two (2) very important formula's have been discussed up to this point. The first formula was how to calculate the time constant of a RC circuit. The formula used for calculating the time constant was TC = R x C. The second formula was how to calculate the pulse width of a signal. The formula used for the calculations of pulse width was $PW = \frac{1}{2F}$. The time constant and pulse width calculations can be used to determine the TC/PW ratio of a RC circuit. The TC/PW ratio will help in determining what type of output waveform is taken from a RC circuit.

Remember the TC tells us how much time is needed for the capacitor to charge to 63% of its applied voltage (E_A).

The PW tells us how much time we have to charge the capacitor to the 63% of E_A.

TC = 10 usec
PW = 100 usec

$$\frac{TC}{PW} = \frac{10}{100} = \frac{1}{10}$$

reduce the fraction

FIGURE 18

To calculate the TC/PW ratio, place the time constant of the circuit over the pulse width of the applied signal. For example, if the time constant of a circuit is 10 usec and the pulse width is 100 usec, the equation for TC/PW ratio should read TC/PW = 10/100.

10/100 reduces to 1/10. Always divide the smaller number into its self and into the larger number.

The TC/PW ratio is 1/10.

$\frac{TC}{PW}$ ratio of $\frac{1}{10}$ or smaller = short

$\frac{TC}{PW}$ ratio higher than $\frac{1}{10}$ and less than $\frac{10}{1}$ = medium

$\frac{TC}{PW}$ ratio $\frac{10}{1}$ or higher = long

FIGURE 19

The TC/PW ratio is divided into three (3) classifications called short, medium, and long.

A TC/PW ratio of 1/10 or less is classified as a short ratio. The short ratio allows the capacitor in a RC circuit plenty of time to charge to the applied signal.

A TC/PW ratio higher than 1/10 and smaller than 10/1 is a medium ratio.

A TC/PW ratio of 10/1 or larger is a long ratio. A long ratio does not allow the capacitor in a RC circuit enough time to charge to the input signal. The TC/PW ratio is a big factor in determining the output waveform of a RC circuit.

TC = 10 usec	PW = 200 usec	$\frac{TC}{PW}$ = ________
TC = 50 usec	PW = 50 usec	$\frac{TC}{PW}$ = ________
TC = 100 usec	PW = 10 usec	$\frac{TC}{PW}$ =
TC = 25 usec	PW = 100 usec	$\frac{TC}{PW}$ = ________
TC = 60 usec	PW = 600 usec	$\frac{TC}{PW}$ = ________

FIGURE 20

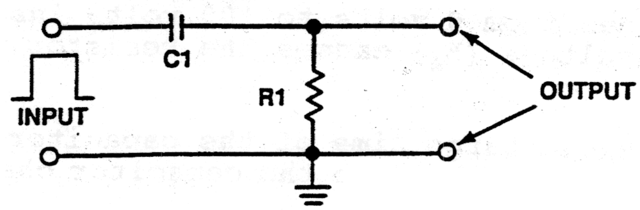
Calculate the TC/PW ratio in each of the problems shown in this view and classify them as short, medium, or long. Remember, TC/PW ratio = $\frac{TC}{PW}$.

TC = 10 usec	PW = 200 usec	$\frac{TC}{PW} = \frac{1}{20}$, short
TC = 50 usec	PW = 50 usec	$\frac{TC}{PW} = \frac{1}{1}$, medium
TC = 100 usec	PW = 10 usec	$\frac{TC}{PW} = \frac{10}{1}$, long
TC = 25 usec	PW = 100 usec	$\frac{TC}{PW} = \frac{1}{4}$, medium
TC = 60 usec	PW = 600 usec	$\frac{TC}{PW} = \frac{1}{10}$, short

FIGURE 21

The answers are shown in this view.

DIFFERENTIATOR



SHORT TC/PW RATIO

FIGURE 24

The differentiator is a form of RC circuit which has three (3) characteristics that separate it from other RC circuits. The first characteristic is the TC/PW ratio, and is short for a differentiator. A short TC/PW ratio is 1/10 or smaller.

The second characteristic of the differentiator is that the output waveform is taken across the resistor.

The third characteristic is that the output waveform is a spiked wave.

The differentiator must have a short TC/PW ratio, and the output must be taken across the resistor. The differentiator shown in this view meets both requirements since the TC/PW ratio is 1/50, and the output is taken across the resistor.

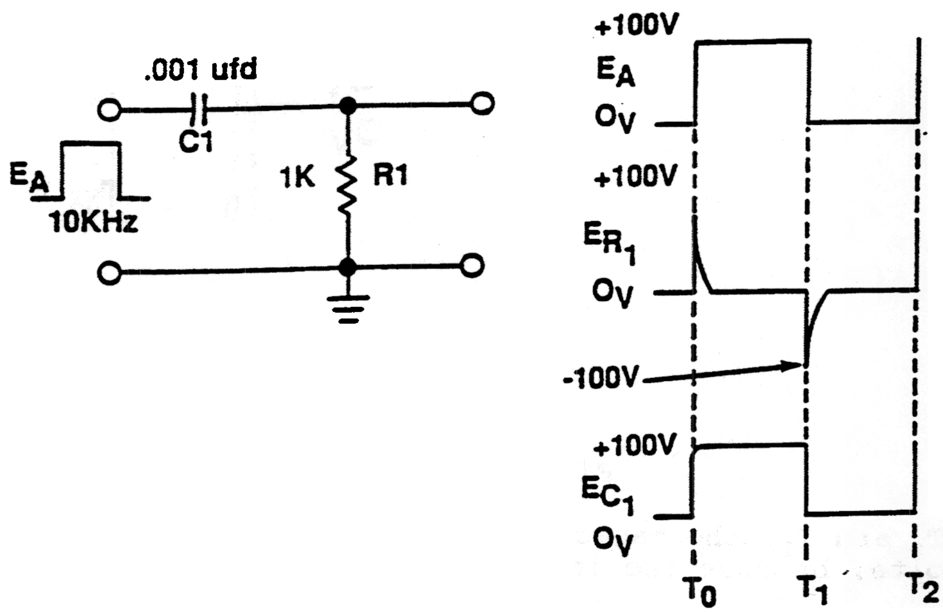


FIGURE 25

When the input signal (E_A) is applied to the circuit at T_0, the voltage level rises from 0 volts to 100 volts instantly. This sudden change in input voltage (E_A) causes the resistor voltage (E_A) to rise to 100 volts.

Due to the quick charge time of the capacitor, the resistor voltage (E_R) will return to 0 because the capacitor charges to the 100 volt input voltage (E_A) quickly.

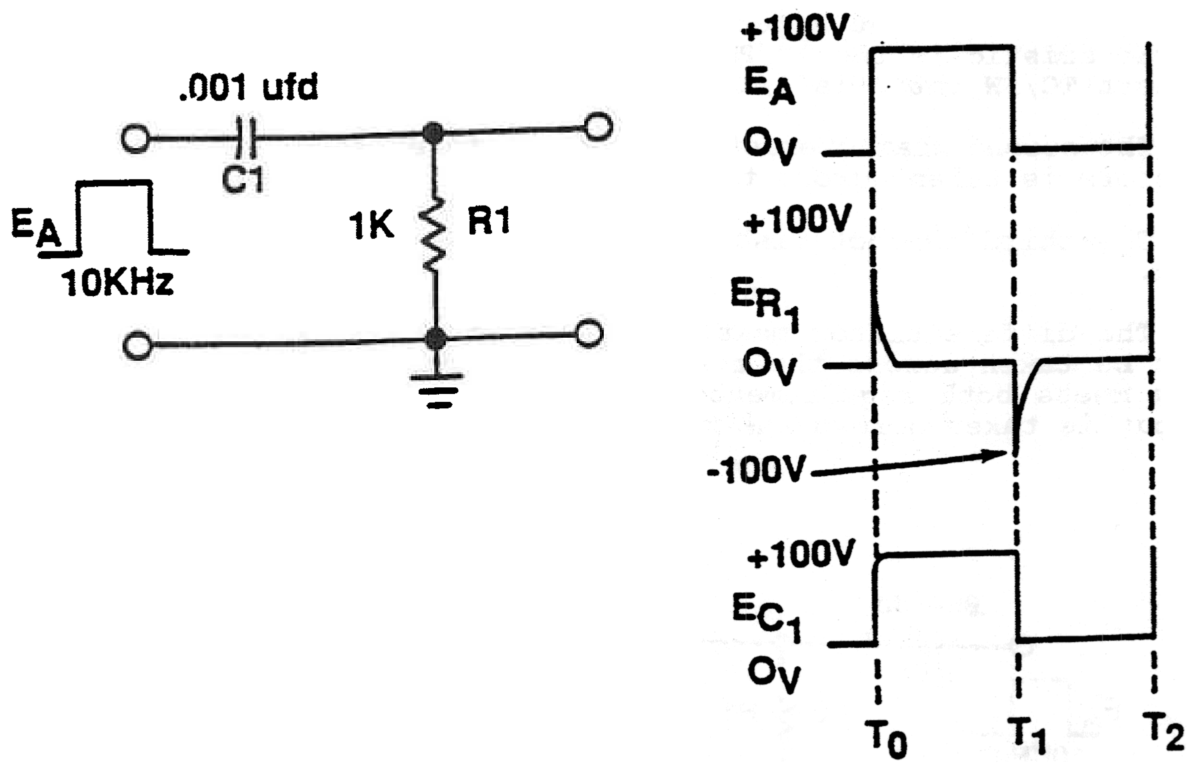


FIGURE 26A

Between T_0 and T_1, the capacitor voltage (E_C) remains at approximately 100 volts, because the input voltage (E_A) is still 100 volts.

Between T_0 and T_1, the resistor voltage (E_R) will stay at 0 volts since the capacitor is charged to the 100 volt applied voltage (E_A).

At T_1, the input voltage drops instantly to 0 volts. This sudden change in input voltage causes the capacitor to discharge.

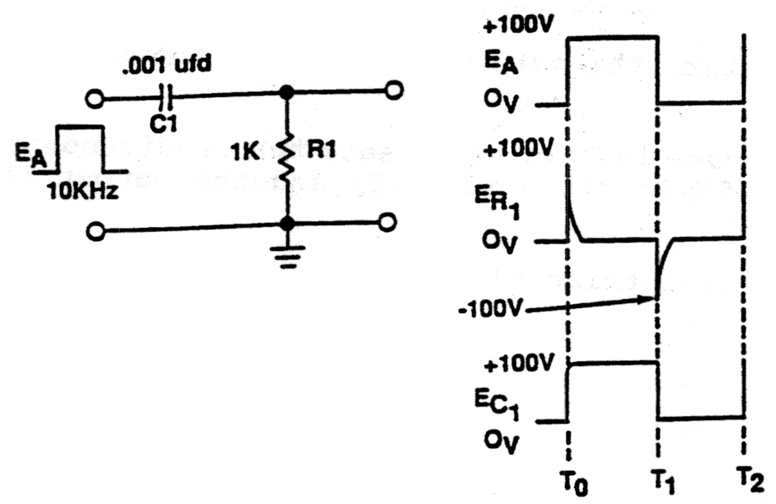


FIGURE 26B

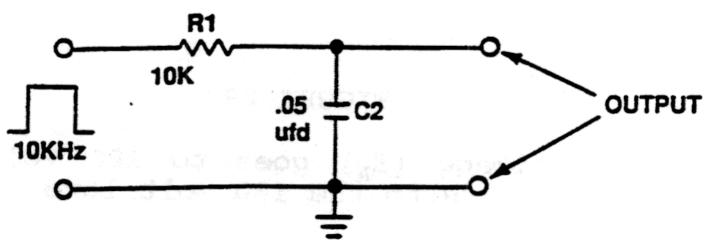
The resistor feels the capacitor discharge, and the resistor voltage (E_R) will go to a -100 volts.

Due to the fast charge and discharge time of the capacitor, the capacitor waveform will resemble the input waveform.

Since the capacitor charges and discharges quickly in a differentiator, the resistor waveform will be a spiked waveform.

At T_2 the process will repeat itself.

INTEGRATOR



TC/PW RATIO of 10/1

FIGURE 27

The circuit shown in this view is an integrator. An integrator has two (2) distinct characteristics which separate it from a differentiator. The integrator must have a long TC/PW ratio.The differentiator has a short TC/PW ratio.

In an integrator, the output waveform is taken across the capacitor.

The circuit shown in this view meets the requirements needed for an integrator. The TC/PW ratio is 10/1, and the output is taken across the capacitor.

The waveform is a triangular wave.

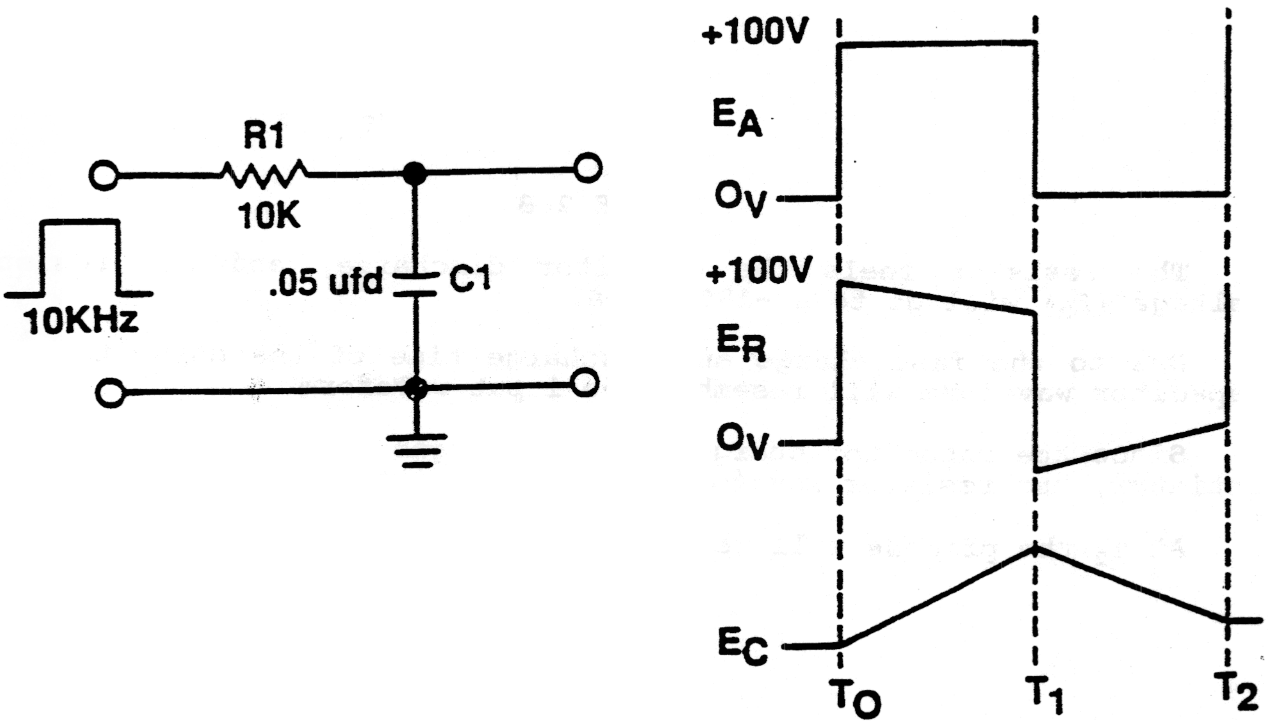


FIGURE 28A

When the input voltage (E_A) goes to 100 volts at T_0, resistor voltage (E_R) will also rise to the 100 volt level.

As the capacitor starts to charge to the 100 volt applied signal (E_A), resistor voltage (E_R) will decrease proportionally as the capacitor increases.

Charge time for the capacitor is slow, and it will not fully charge to the applied voltage (E_A) because of the long TC/PW ratio.

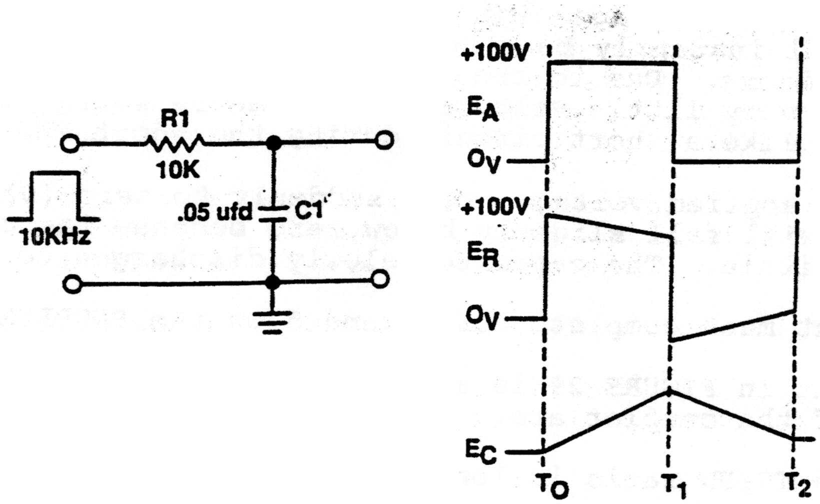


FIGURE 28B

At T_1 the input voltage (E_A) goes to 0 volts, and this causes the capacitor to begin discharging. The resistor voltage (E_R) will go below 0 volts because it feels the capacitor discharge.

The resultant waveform is a distorted square wave at the resistor, and a triangular wave at the capacitor.

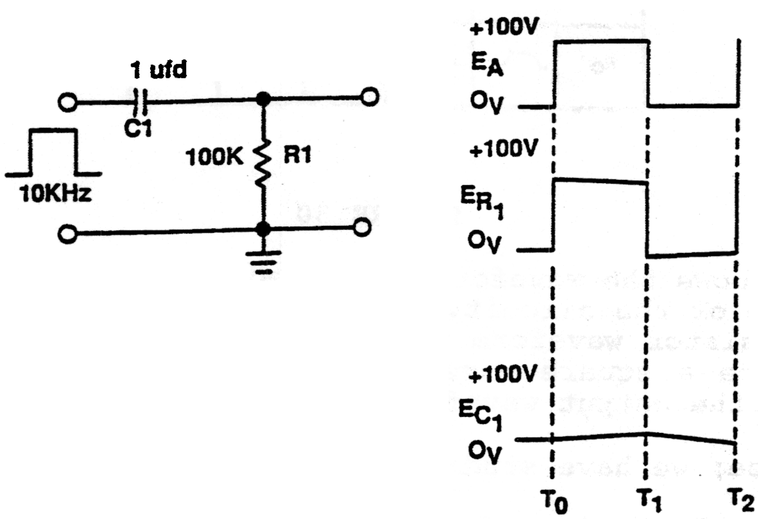


FIGURE 29

When the input voltage (E_A) goes to 100 volts at T_0, capacitor voltage E_{C1} will instantly be zero (0) volts dropping all of the 100V across the resistor. Due to the largeness of TC_1, the capacitor will only charge to very little voltage before the PW ends. In effect the capacitor acts like a short circuit during the short PW.

At T_1, the applied voltage drops suddenly to zero (0). The voltage across R_1 will fall slightly below zero because the capacitor has charged very little. The capacitor slowly discharges to zero (0).

The student must complete JOBS 4 and 5 on the PROBLEM SHEET.

The circuit in FIGURE 29 is a coupling circuit. The three characteristics of the coupler are:

First, the TC/PW ratio is long (2000/1)

Second, the output is taken across the resistor.

Third, in a good coupler the output waveform will look like the input waveform.

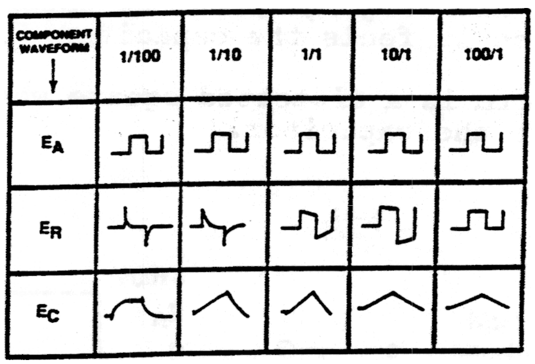


FIGURE 30

This view shows the waveforms produced by RC circuits according to the TC/PW ratio of the circuit. If a RC circuit has a TC/PW ratio of 1/1000, the resistor waveform will be a spiked wave. The capacitor waveform will be a square wave rounded at the edges. As the TC/PW ratio changes, the output waveforms will also change.

To summarize; we have studied three types of RC circuits.

First, the calculation of time constant,

$$TC = RC$$

Second, the calculation of pulse width,

$$PW = \frac{1}{2F}$$

Third, the calculation of time constant to pulse width ratio or TC/PW.

Fourth, we were able to define the types of circuits based on three characteristics.

The characteristics of the;

Differentiator
- short TC/PW ratio 1/10 or less.
- output taken across the resistor.
- waveform is a spiked wave.

Integrator
- long TC/PW ratio 10/1 or higher.
- output taken across the capacitor.
- waveform is a triangular wave.

Coupler
- very long TC/PW ratio 100/1 or higher.
- output taken across the resistor.
- waveform is like the input.

Compare the characteristics as shown above with those in FIGURE 30

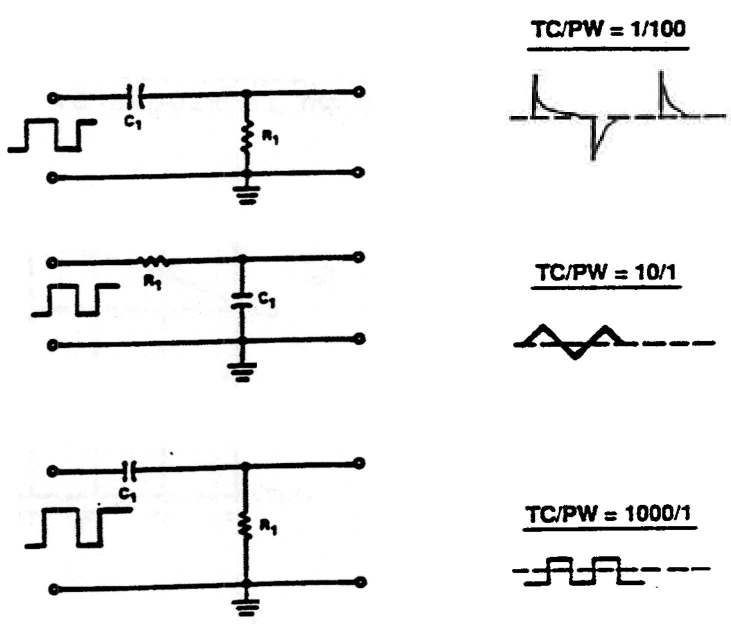


FIGURE 31