Module

4

DC Transients

What happens when things change.

What you'll learn in Module 4.

4.1 Resistors in DC Circuits

Transient events in DC circuits.

The difference between Ideal and Practical circuits

Transient current and voltage relationships in a simple resistive circuit.

4.2 Capacitance and Resistance in a DC Circuit

Transient voltage and current relationships in a simple CR circuit

4.3 CR Time Constant

The Time constant of a CR circuit.

Calculations involving time constants in a simple CR circuit.

4.4 Inductance and Resistance in DC Circuits

Transient voltage and current relationships in a simple LR circuit

4.5 LR Time Constant

The Time constant of a LR circuit.

Calculations involving time constants in a simple LR circuit.

4.6 DC Transients Quiz

Module 4 Quiz: Revision questions on DC transient events.

Introduction

AC Theory could be described as "The study of electronic circuits in which things are always changing". Voltages, currents and other quantities in AC circuits are in a continual process of change.

Before studying AC circuits in depth, Module 4 looks at what happens when conditions suddenly change (called transient events) in DC circuits, so that what is learned here can be used as a foundation for later modules.

Each time a switch is clicked or an input is connected, circuit conditions change, but only for short time, during these brief transient events, components and circuits may behave differently to the way they behave under normal "static" conditions.
This module describes the effects of transient events on resistors, inductors and capacitors.

Module 4.1 Resistors in DC Circuits

Transient Events

In AC circuits, voltage and current conditions are continually changing. We therefore need to include the effects of time and transient (passing) events on circuit conditions. A transient event is something that happens over a period of time, such as a switch opening or closing.

Fig 4.1.1 Ideal circuits in a practical world.

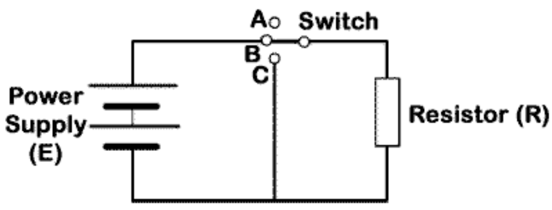

Fig 4.1.1

A theoretical or "ideal" DC circuit such as illustrated (right) contains only resistance. Every practical (real) circuit however, contains at least some capacitance and some inductance as well as resistance. Any circuit must contain metal conductors that will have some inductance. Also components or wires that are near others, with an insulating gap (air and/or plastic) between them, must effectively be capacitors. Therefore a purely resistive circuit only exists in theory. A practical circuit such as that in Fig. 4.1.1 can have one property, such as resistance much greater than the capacitance or the inductance naturally present, so these can be ignored for theoretical purposes, and the circuit considered as having only resistance. To indicate this, the circuit is called an "ideal circuit". That is, one that contains only one pure property, in this case resistance.

Fig 4.1.2 What happens in the circuit.

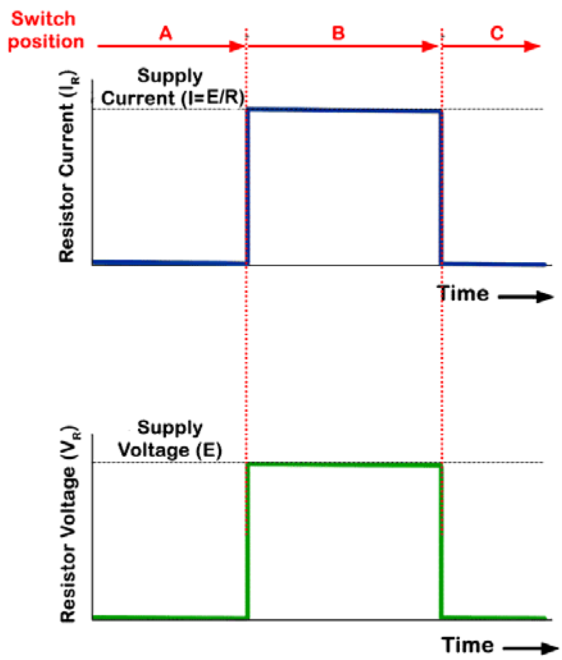

Fig 4.1.2

The transient operation of the circuit Fig.4.1.1, during switch operation, is shown in Fig. 4.1.2.

As the switch closes on contact B, the amount of current flowing, which has previously been zero, will instantly rise to a maximum level. This will make the current(I) equal to the battery EMF (E) divided by the resistance (R). That is;

I=E/R

Which is an expression of Ohms law that can be used to calculate the value of current at any time, given the other two values.

Suppose E=10V and R=5Ω

This gives I=10/5 = 2Amperes.

And if R is increased to 10Ω while E remains the same,

Then I=10/10 = 1Ampere.

Increasing the resistance has reduced current flow.

If the EMF supplying the circuit is increased, while the resistance remains the same, the current increases.

Fig. 4.1.2, shows what happens to the voltage and current whilst the switch is closed, and then opened again. Both current and voltage rise immediately to a steady value as the switch is closed, then fall immediately to zero when the switch is opened.

The voltage across the resistor (V_R) whilst the switch remains closed is given by:

$V_R = I \times R$

The difference between E and V for voltage.

In a practical circuit it is possible for E and V_R to be slightly different. This is because any power supply, such as a battery will have an internal resistance, designated (r), which although usually very small, will be in series with the circuit resistance R. This can make E and V slightly different, so to be totally accurate, E and V should be shown as separate quantities, which would modify the formula for current to:

$I = E/(R+r)$

The formula for V_R remains V V_R = IR but the current (I) would be slightly less because of the effect of r in the formula for current.

The resistance R can be calculated by :

$R = V_R / I$

Module 4.2 Capacitance and Resistance in DC Circuits

The voltage across a capacitor cannot change instantaneously as some time is required for the electric charge to build up on, or leave the capacitor plates.

The CR circuit

In Fig 4.2.1, when the switch is changed from position A to position B, the capacitor voltage tries to charge to the same voltage as the battery voltage, but unlike the resistor circuit, the capacitor voltage can´t immediately change to its maximum value, which would be (E).

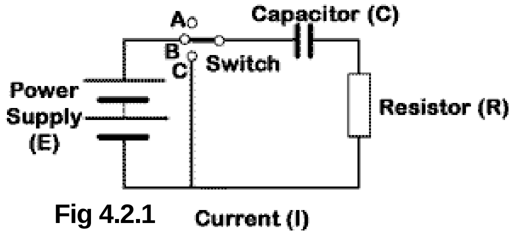

Fig 4.2.1

Charging and Discharging the Capacitor

As soon as the switch reaches position B, the circuit current rises very rapidly, as C begins to charge (Fig 4.2.2). Although the voltage is still low, its rate of change is large and the voltage graph is initially very steep, showing that the voltage is changing in a very short time. As the capacitor charges, the rate of change of voltage slows and charge slows as the charging current falls. The curve describing the charging of the capacitor follows a recognisable mathematical law describing an exponential curve until the current is practically zero and the voltage across the capacitor is at its maximum.

If the switch is now changed to position C, the supply is disconnected and a short circuit is placed across C and R. This causes the capacitor to discharge through R. Immediately maximum current flows, but this time in the opposite direction to the that during charging. Again an exponential curve describes the fall of this negative current back towards zero. The voltage also falls exponentially during this time, until the capacitor is fully discharged.

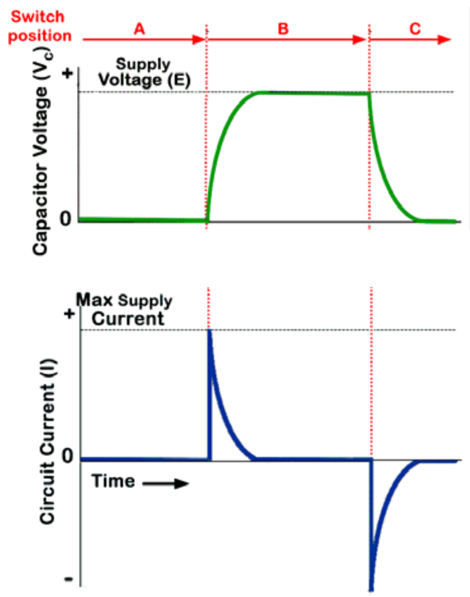

Fig 4.2.2

Opposites

Compare the graphs describing the actions of the CR circuit described above and the LR circuits in section 4.4. Notice that the curves described are the same, but the voltage and the current curves have "changed places". These "opposite" effects of L and C will be noticeable in many of the actions described in later modules.

Module 4.3 CR Time Constant

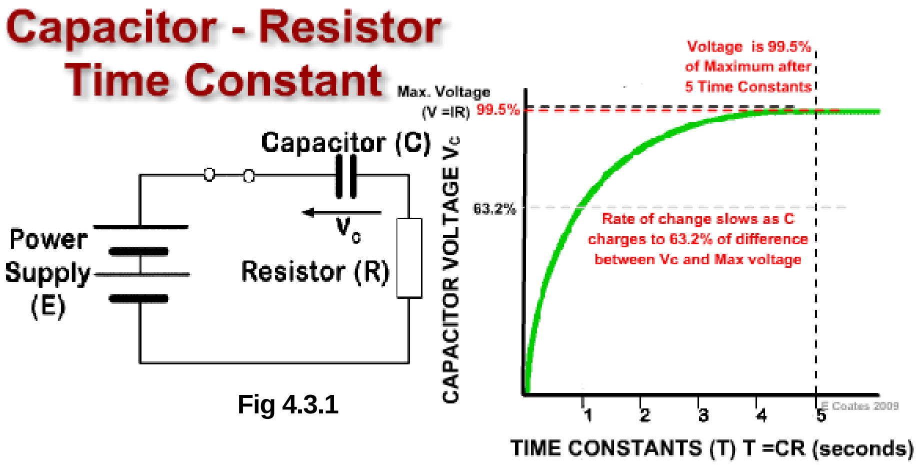

Fig 4.3.1

When a voltage is applied to a capacitor it take some amount of time for the voltage to increase in a curve that follows a mathematically "exponential" law to its maximum value, after which, the voltage will remain at this "steady state" value until there is some other external change to cause a change in voltage. From the instant the voltage is applied, the rate of change of the voltage is high, and if it was to continue in a linear manner, then V_C would reach its maximum value in a time equal to one time constant (T), where T (in seconds) is equal to C (in Farads) multiplied by R (in ohms), see fig 4.3.1. above. That is:

T = CR

Fully Charged?

After about 5 time constant periods (5CR) the capacitor voltage will have very nearly reached the value E. Because the rate of charge is exponential, in each successive time constant period V_C rises to 63.2% of the difference in voltage between its present value, and the theoretical maximum voltage (V_C = E). Therefore the 63.2% becomes a smaller and smaller voltage rise with each time constant period and although, for all practical purposes V_C = E in fact V_C never quite reaches the value of E.

About the Formula

For this reason the time when V_C = E cannot be accurately defined, therefore some other accurate time measurement must be used to define the time it takes for V_C to reach some given level. One simple solution would be to say that a time constant will equal the time it takes for V_C to reach half the supply voltage. This would work but then the formula for T would not be as easy to remember as CR (or L/R), it would also make calculations involving time constants more difficult. Because time constant calculations are important, and often needed, it is better to make the definition of the time constant (T) in a CR circuit:

THE TIME TAKEN FOR THE VOLTAGE ACROSS A CAPACITOR TO INCREASE BY 63.2% OF THE DIFFERENCE BETWEEN ITS PRESENT AND FINAL VALUES.

A slightly more complicated definition, but this provides a much easier formula to remember and to work with, **T = CR.**

Discharging C

When the capacitor is discharging the same CR formula applies, as the capacitor also discharges in an exponential fashion, quickly at first and then more slowly. **During discharge the voltage will FALL by 63.2% to 36.8% of its maximum value in one time constant period T.**

Module 4.4 Inductance and Resistance in DC circuits.

Fig. 4.4.1 The LR Circuit with Inductance (L) and Resistance (R)

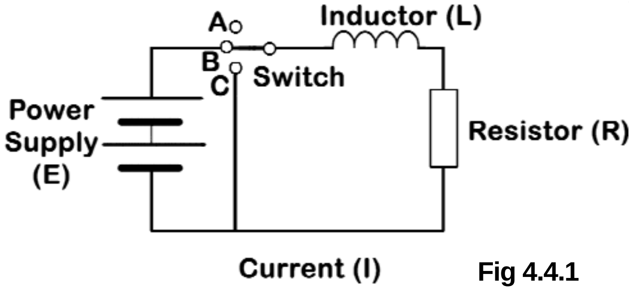

Fig 4.4.1

In a circuit which contains inductance (L), as well as resistance (R), such as the one shown in Fig. 4.4.1, when the switch is closed the current does not rise immediately to its steady state value but rises in EXPONENTIAL fashion. This is due to the fact that a BACK EMF is created by the change in current flow through the inductor. This back EMF has an amplitude which is proportional to the RATE OF CHANGE of current (the faster the rate of change, the greater the back EMF) and a polarity which opposes the change in current in the inductor that caused it initially. The back EMF is produced because the changing current in the inductor causes a changing magnetic field around it and the changing magnetic field causes, in turn, an EMF to be induced back into the inductor. This process is called SELF INDUCTION.

Current Through an Inductor

Because the back EMF opposes the rapid change in current taking place in the inductor, the rate of change of current is reduced and what would be a vertical line on the graph (Fig. 4.4.2) becomes a slope. The rate of change of current through the inductor is now less, so a smaller back EMF is produced. This allows the current to increase further. The relationship between the changing current and back EMF produces a curve which always follows a mathematical law to produce a particular shape of curve i.e. an exponential curve. When the switch is opened, the current decays in a similar exponential manner towards zero.

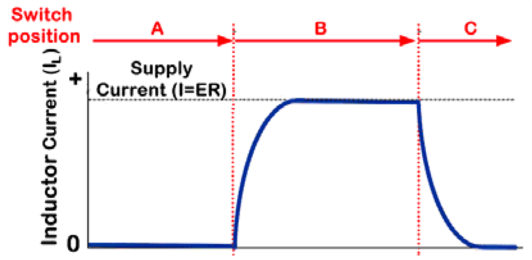

Fig 4.4.2

Voltage Across an Inductor

Looking at Fig. 4.4.3 which shows the voltage (VL) across the inductor (L) we can see that at switch on, the voltage immediately rises to a maximum value. This is because a voltage is being applied to the circuit and little or no current is flowing because L is effectively (for a very short time) a very high resistance due to the back EMF effect. The full supply EMF is therefore developed across the inductor. As current begins to flow through L however, the voltage VL decreases until a point is reached where the whole of the battery voltage is being developed across the resistor R and the voltage or potential difference (pd) across L is zero.

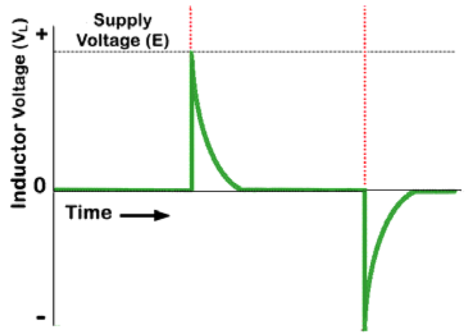

Fig 4.4.3

When the current is switched off, the rapidly collapsing magnetic field around the inductor produces a large spike of induced current through the inductor in the opposite direction to the current that was flowing before switch−off. These rapid changes in current as the switch opens can cause very large voltage spikes, which can lead to arcing at the switch contacts, as the large voltage jumps the gap between the contacts. The spikes can also damage other components in a circuit, especially semiconductors. Care must be taken to prevent these spikes that can occur in any circuit containing inductors. In some circuits however, where high voltage pulses are required, this effect can also be used to advantage.

Module 4.5 LR Time Constant

When a current is applied to an inductor it takes some time for the current to reach its maximum value, after which it will remain in a "steady state" until some other event causes the input to change. The time taken for the current to rise to its steady state value in an LR circuit depends on:

- The resistance (R)

This is the total circuit resistance, which includes the DC resistance of the inductor (RL) itself, plus any external circuit resistance.

- The inductance of L

Which is proportional to the square of the number of turns, the cross sectional area of coil and the permeability of the core.

The LR Time Constant

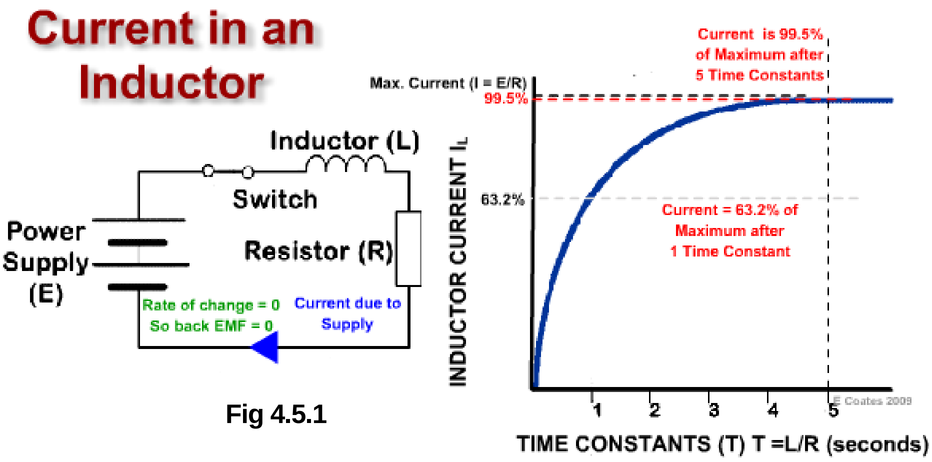

Fig 4.5.1

An Inductor opposes CHANGES in current flow

When the circuit in Fig 4.5.1 is switched on current changes rapidly from zero, this sudden change creates a rapidly expanding magnetic field around the coil, and in doing so induces a voltage back into the coil. This induced voltage (called a back EMF) creates a current flowing in the OPPOSITE direction to the original current. The result of this is that the initial rate of change of the circuit current is reduced. If this initial rate of change were to continue in a linear fashion, the current would reach its maximum or steady "state value" in a time given by:

T = L/R seconds.

T is the TIME CONSTANT and is measured in seconds

L is the INDUCTANCE and is measured in Henrys

R is the TOTAL CIRCUIT RESISTANCE and is measured in Ohms.

Seconds and Henrys are usually far too large for most electronics measurements, and milli and micro units are commonly used, but remember when calculating to convert any of these sub units to seconds or Henrys for use in formulae.

The rise in current is not linear however, but follows a curved "exponential" path, and in one time constant the current will have only risen to 63.2% of its maximum (steady state) value. After five time constants it will reach 99.5%, which is regarded as its maximum value

Discharge

If the circuit is switched off, current does not immediately fall to zero, it again falls exponentially, and after one time constant period will have reached 36.8% of the previous steady state value (i.e. the steady state value -63.2%). It is considered to reach zero in five time constant periods.

The Exponential Curve

The change of current in an inductor in response to a step change in input is exponential. For a series of equal time periods, the current charges the inductor towards its maximum value, by a percentage of the remaining difference between the present and maximum values. So although this difference continues to shrink, the extra charge built up during each time period also shrinks. The outcome of this is that the current can never ever reach the maximum!

Why 63.2%?

If the current never reaches its steady state value, this presents a problem of how to measure the time taken to fully charge. This is why the idea of a time constant, (the time it takes to charge by 63.2%) is used. Why choose 63.2% when there are easier numbers such as 50% that could be used? Well 50% would be nice but would create an awkward formula with which to calculate the time taken.

It's Simple!

It so happens that using 63.2% (which is not too different from 50%) results in a nice simple formula of L/R for the inductor time constant, and CR for the capacitor time constant. This greatly simplifies calculations, and because the current will have reached 99.5% of the steady state value after 5 time constants, this is near enough in practice to consider that the maximum value has been reached.

Module 4.6 DC Transients Quiz

What you should know.

After studying Module 4, you should:

Be able to describe transient events in DC circuits.

Be able to describe transient voltage and current relationships in a simple LR, CR and resistive circuits.

Be able to describe transient events in CR and LR combinations in DC circuits.

Be able to calculate LR and CR time constants.

Try our quiz, based on the information you can find in Module 4. Check your answers on line at: http://www.learnabout-electronics.org/ac_theory/dc_ccts06.php

1.

When the switch in Fig. 4.6.1 is closed, how long will it take for the capacitor voltage to reach its steady state value?

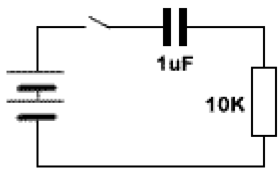

Fig 4.6.1

a) 1ms b) 10ms c) 50ms d) 500us

2.

When the switch in Fig. 4.6.2 is closed, how long will it take for the capacitor voltage to rise to 6.3 volts?

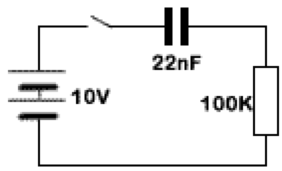

Fig 4.6.2

a) 2.2ms b) 220ms c) 2.2s d) 120ms

3.

A CR circuit connected to a DC supply will, for a time after a voltage is applied to it, behave as though the capacitors were very ________ value resistances, but these effects will disappear after a time approximately equal to _______ time constant(s). The missing words in this sentence are:

a) Low and one b) Low and five c) High and one d) High and five

4.

Refer to Fig. 4.6.3: What will be the approximate voltage across the inductor 100ns after the switch is closed?

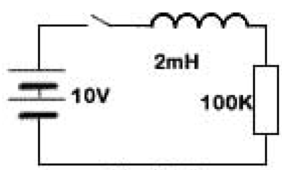

Fig 4.6.3

a) 6.3V b) 7.07V c) 0V d) 10V

5.

Calculate the time constant of a circuit consisting of a 15mH inductor and a 470Kohm resistor.

a) 32ns b) 7s c) 31.9ms d) 70ms

Continued:

6.

If a simple LR circuit consisting of a 20Ω resistor in series with a 100mH inductor is connected to a 10V supply, from which it draws a current of 500mA after it has reached its steady state. How long after switch on, will the current take to reach 316mA?

a) 5ms b) 2ms c) 2s d) 500ms

7.

An ideal circuit is a useful theoretical tool because:

a) It uses real components

b) It is drawn in a simplified format

c) It is designed to give optimum results

d) Real but unimportant factors can be ignored.

8.

In the formula I = E/(R+r) the quantity r is added to compensate for:

a) The internal resistance of the power supply.

b) The resistance of the switch contacts.

c) The delay caused by the switch closing and opening.

d) The tolerance rating of the resistor.

9.

The back EMF produced as an inductor charges up is proportional to:

a) The supply EMF

b) The charging current

c) The voltage across the inductor

d) The rate of change of the applied current

10.

The back e.m.f produced when an inductor is first connected to a DC supply is..

a) Proportional to the applied voltage.

b) Inversely proportional to the value of inductance.

c) Initially high, and then gradually reduces.

d) Initially low, and then gradually increases.