A.C.THEORY KIT

Cat: EM0060-001

KIT CONTENTS:

DIGITAL SIGNAL GENERATOR	2 Henry INDUCTOR	2 Henry INDUCTOR

DIGITAL MULTIMETER	300-0-300mA AMMETER	10-0-10V VOLTMETER
CONNECTION CABLES		

CAPACITOR 5µF	CAPACITOR 10,000µF	RESISTOR 25 Ω	RESISTOR 500 Ω	SWITCH TWO WAY
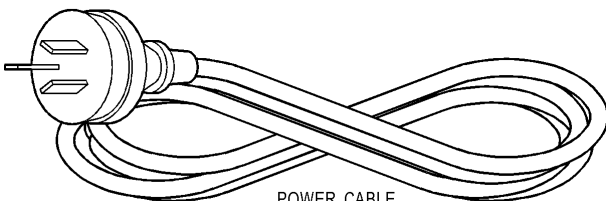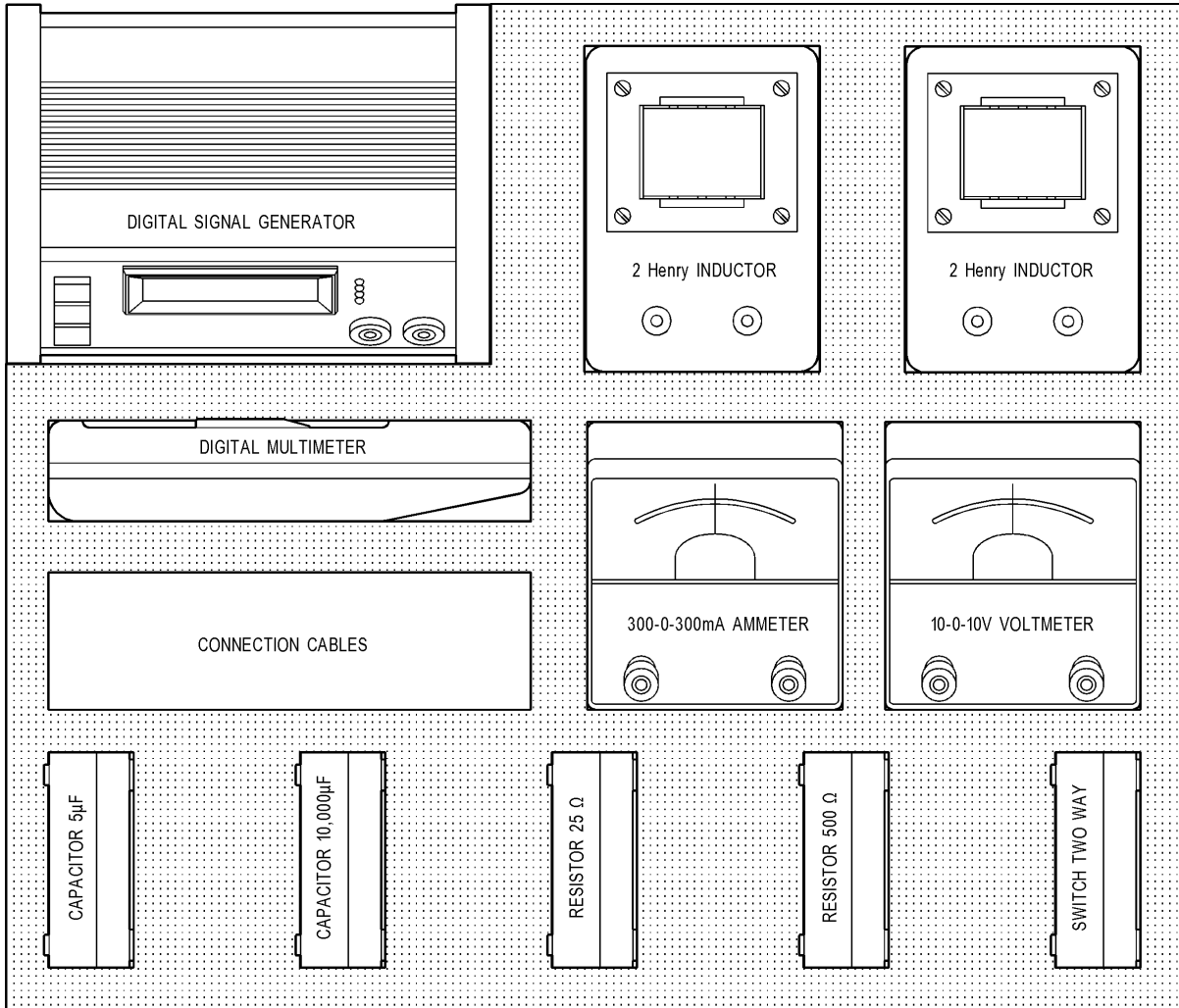
POWER CABLE
ON TOP OF CONNECTION CABLES

GENERAL DESCRIPTION:

This kit is designed to perform important basic experiments with A.C. (alternating current) electricity. To measure and study Resistors, Inductors and Capacitors and their Resistance, Impedance and Reactance together with Series and Parallel resonance and Power Factor.

Including the study and visual observance of Phase relationships between Voltage applied and the Current flowing through an Inductor and a Capacitor.

DESIGN FEATURES OF THE KIT:

- The kit is complete with an excellent, high power Wave Generator, three meters and all cables required to perform all experiments. No ancillary equipment is required.

- All the equipment is fitted into one strong carry case with transparent lid.

- Meters in the kit include a centre-zero ammeter and a centre-zero voltmeter together with a good quality digital meter.

- The component values have been chosen to provide the best results.

- The measurements and experiments are extremely practical and a thorough understanding of this theory will assist anyone entering the electrical profession.

- All cables have stackable banana plugs moulded to the cables for maximum strength and reliability.

KIT CONTENTS:

Wave Generator: The IEC 'Mini Wave' digital frequency generator runs from 220/240V.AC. 50/60Hz. It is microprocessor controlled with a bright LED display and an output voltage of 10V peak/peak. Waveforms can be selected as Sine, Square, Triangular and Sawtooth.

Output voltage is fixed at 10V.peak/peak with an output impedance of 0.5 ohm. **NOTE:** 10 Volt peak/peak equates to 5.0 Volt peak and this equates to 3.54 Volts RMS.

By pressing up/down buttons, the frequency is adjustable from 0.5 to 50.0 Hz in steps of 0.1 Hz and from 50.0 Hz to 100 Hz in steps of 0.2 Hz and from 100 to 200 Hz in steps of 1 Hz.

Other kit contents are:

- 2x Inductors: Large inductors of approx. 2 Henry inductance. DC resistance approx. 8ohms.

- 1x Capacitor (large): Approx 10,000uF, 10V, bi-polar (can accept AC voltage)

- 1x Capacitors (small): 2x Small AC capacitors, 5uF+5uF, both in a single plastic housing.

- 1x Resistor: 25 ohms, 550mA max, in plastic housing.

- 1x Resistor: 500ohm, 60mA max, in plastic housing.

- 1x Switch: Single pole 2 way, in plastic housing.

- 1x Student Meter, 300/0/300mA analogue, centre zero.

- 1x Student Meter, 10/0/10V.DC. analogue, centre zero.

- 1x Meter, digital, for ohms, capacitance and measurement of AC amps and AC volts.

- Set/10 Cables: 1 pack of 10 cables with 4mm stackable banana plugs, moulded to cables.

- Instruction & Experiment booklet.

GLOSSARY OF TERMS USED IN THIS MANUAL:

AC: Means Alternating Current. This is current that flows both forward and backwards following a sinusoidal waveform. AC does not have a positive or negative, therefore red and black terminal and wire colours are usually not used. Traditional terminal colours for AC may be Blue or Yellow.

AMPS: This is the name or unit given to the flow of electricity or electrical current.   If one Volt of potential is applied to one Ohm of resistance, then one Amp of current flows.   If currents are small, the unit can be milliamps or 'mA' (one thousandth of an amp). If currents are very small, the unit can be microamps or 'uA' (10^{-6} or one millionth of an amp) or nano-amps (10^{-9}) or pico-amps (10^{-12}).

AVERAGE: The average value of a sine wave voltage or current is: Peak value x $2/\Pi$. This equals the Peak value of the Sine wave x 0.636.   See also RMS.

CAPACITOR: A capacitor is a device consisting of metal plates of a large surface area and an insulation between them of very thin dimension. A capacitor can store electric charge when voltage is applied and current flows to charge the plates. If there is zero resistance in the circuit, the capacitor charges instantly. If there is resistance, the capacitor charges over time. When the plates are fully charged to the potential of the voltage source, the charging current stops. At a later time, this energy can be released, or 'discharged' to perform a function.

CAPACITOR AS A FILTER: Capacitors are commonly used in circuits that rectify AC to DC to try to make rectified DC smoother. When the 'hump' in the waveform falls towards zero, the energy stored in the capacitor is discharged to try to fill the gap between the 'humps' in the waveform. As the 'hump' in the waveform rises again, the capacitor is re-charged. This occurs 100 times per second and when used in this manner, they are called 'filter capacitors'. Large filter capacitors are polarised and are designed to be connected only to a DC voltage source. They are called 'electrolytic' capacitors. CAUTION::: If polarised electrolytic capacitors are connected to AC or if they are connected backwards to the DC voltage, they get hot and burst with a loud 'bang'.   Some capacitors are designed for AC but these are not usually electrolytic type and are much smaller capacitance.   There are many types of capacitors for various voltages and uses.

CAPACITOR AS AN OSCILLATOR: Capacitors are commonly used in circuits where they are charged and then discharge through an inductive device that causes them to charge again so that the cycle repeats etc. This means they are charged and discharged maybe thousands of times per second. This arrangement is called an Oscillator.

 CAPACITOR AS A PHASE CORRECTION DEVICE: In resistive circuits, the current flows in phase (at the same exact time) as the voltage is applied.   In Inductive circuits, on each AC cycle, the current flows through the inductor later in time to the applied voltage (not in phase) and a Capacitor has a current that flows earlier in time to the voltage.   When an inductive circuit needs to make the phasing closer to 'in phase', a capacitor connected in parallel to the inductor will bring the current and voltage back to be closer to 'in phase'.   See 'Power Factor'.

CHOKE or INDUCTOR: A Choke, sometimes called an Inductor, is an AC device.   For very high frequencies (radio frequencies etc) the coil is air or ferrite cored, but for low frequencies it is usually fitted with a laminated iron core. The magnetic field in the iron caused by the current through the coil also cuts the turns of wire in the same coil and causes a reverse voltage in the winding that opposes the applied voltage. This tries to stop the flow of current through the coil and this effect is called Reactance.   If the iron core is removed from the coil, the Reactance is reduced and the AC current increases greatly.

CORE: Means the iron shape that is used in an Inductor or Choke, or the iron to couple the magnetic field between two or more coils. A magnetic field can exist much more easily in an iron core than it can in air. The iron circuit of AC devices is normally laminated. See "Laminations". When an iron core is used inside the coils, the induction effect is much more efficient.

CURRENT: This is the conventional flow of electricity through a conductor. It is caused by an EMF or voltage causing electrons to flow in a conductor if a circuit is closed. In DC circuits, the current flows in a conductor 'in phase' (see glossary) with the voltage. In AC circuits this is not always the case. The IEC 'AC Theory kit' is designed to study this phenomenon.

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DC: Means Direct Current. This is current that flows in one direction only. It might be a smooth, non-varying current from a battery, or it might be a pulsating current which is obtained when AC is rectified to DC. The AC sine wave is converted by the rectifier to flow in one direction, but rises and falls 100 times per second from zero to maximum in the shape of half of a sine wave. DC has a polarity and normally red means positive and black means negative. Current flows in a DC circuit from positive to negative.

EMF: Means Electro Motive Force. This is the voltage generated in a conductor when it moves across a magnetic field. Voltage is like the pressure of electricity and, when the circuit is closed, a current is forced through the conductors because of the presence of an EMF. The amount of current flowing depends on the magnitude of the EMF and the resistance of the circuit (Ohm's Law).

FIELD: This is a general name given to magnetic lines of force either in an iron core or in air.

FILTER: When AC voltage is rectified to create DC, the DC is not smooth like a battery. It follows the AC sine wave shape and, although it does not reverse direction, it rises from zero volts up to a peak and falls again 100 times per second (full wave rectification) or 50 times per second (half wave rectification). A filter, which is usually a large value capacitor connected across the DC, charges up to the peak voltage and discharges into the load to try to level out the humps and make it closer to a smooth DC.   The effect is best seen on an oscilloscope.

FLUX: Is a general term meaning the magnetic field present usually in an iron core.

FREQUENCY: This is the number of times per second that the AC wave passes through one full cycle of rising from zero to maximum, then falling through zero to minimum and then rising to zero again.   The unit is Hertz.   Normal mains power in Australia has a frequency of 50Hz.   Other countries such as USA and Canada (and many others) use a 60Hz power system.

IMPEDANCE: In the world of DC, resistance (ohms) is the factor that controls the current in a circuit. In the world of AC, there is a mixture of both Resistance and Reactance which alter the flow of current through an AC circuit.   The term Impedance means the vector combination of these two phenomena. The term 'Low Impedance' means a circuit that has only small total resistive effect to an AC current flow. Impedance is the vector resolution of Resistance, Inductive Reactance and Capacitive Reactance. $'Z' = \sqrt{R^2 + (X_L - X_C)^2}$

INDUCTANCE: This is the measurement of a coil's inductive effect in Henrys. Inductance depends on the number of turns in the coil and the amount of iron in the core. Coils of low inductance (micro Henrys) are used in radio sets for tuning stations and coils of larger inductance (milli Henrys or Henrys) are used as Chokes for power supply filters or high power oscillators and special equipment.

INDUCTION: Means the inducing of a voltage in a coil of wire by the application of a magnetic field from either a magnet or another coil of wire.   The coils of wire are usually not electrically connected.

INDUCTOR: An inductor is a coil of many turns of copper wire mounted usually on an iron core (see Choke). An inductor has Inductance and, being made from wire, always has some resistance too.

LAMINATIONS: Iron cores in an AC device are made from thin strips of iron instead of from solid blocks of iron. These thin strips are called laminations and are insulated electrically so that electrical current cannot flow from one to another. The magnetic flux can exist in the iron, however the laminations do not permit circulating electric currents to flow in the iron.

LEAKAGE: This is stray magnetic field that appears outside the iron core. Any field leaking outside the iron core cannot be used by the transformer in driving the secondary coil. Transformer design tries to keep magnetic leakage to a minimum.

LOAD: The term 'load' is used for any circuit that draws power from a power source.   If a resistor is connected to a battery so that current flows, the resistor can be called the 'battery's load'.   The current drawn by the resistor can also be called the 'load' on the power source.

LOSSES: This is the name given to energy provided by the Primary coil to the system but not available as usable energy from the secondary coils. Transformer losses include:

- The energy required in magnetising and de-magnetising and reversing the magnetisation in the core 100 times per second. Special iron used for transformers has low losses.
- Resistance in the copper wire of the windings causing voltage loss and heat generated.
- Circulating currents in the iron core causing heating of the iron.
- Loss of magnetic field (leakage) into the air from the iron core.

MAGNETISING CURRENT: This is the current drawn from the power source by the primary coil required to magnetise the iron core and to overcome leakage and losses. Transformer design tries to keep the magnetising current as small as possible because it is wasted energy from the power source and causes unwanted heating in the primary coil.

PARALLEL CONNECTION: When two or more devices are connected so that the current divides and flows through side-by-side paths, they are said to be connected 'in parallel'.   The total current from the source is the sum of the parallel currents.

PEAK VOLTAGE: Unfiltered DC voltage is a sine wave shape that rises to a peak value and falls to zero volts 100 times per second. When a DC voltmeter meter is placed on the DC, it shows the average DC voltage (not the peak voltage). If a capacitor is placed on the output when there is no load connected to the power supply, it will charge to the peak value which is the highest point of the sine wave. The voltmeter will show this higher peak voltage (average x 1.414). When a load is placed on the power supply, the capacitor will discharge this extra energy into the load as the sine wave falls 100 times per second and the voltmeter will then show the average voltage again. But this will be a higher average than before because the capacitor adds extra energy to the load.

In the case of AC, peak voltage is the height of the AC Sine wave at its highest point in either the positive or negative direction.   See 'RMS'.

PHASE: If you raise both arms and lower them together, they are 'in-phase'. If one arm rises as the other arm falls, they are 'out of phase'. The timing relationship of two voltages or two currents or a voltage compared to a current is called the 'phase relationship'. In the world of DC, currents and voltages are usually 'in phase'.   This is not always the case in the world of AC.

As an AC voltage rises in a coil with an iron core, the current through the coil rises slightly later than the voltage. Therefore the magnetic field also rises slightly later than the voltage. ZZZZ The voltage induced in a secondary coil therefore appears at a different instant when compared to the applied voltage. Look at these voltages on a double beam oscilloscope.

In inductors, the current lags behind the voltage by 90° in time. In Capacitors, the current leads the voltage by 90°. This kit is to study this phenomenon.

 If a secondary coil is wound the same direction (clockwise or anti-clockwise) as another secondary coil, the AC voltage on these two coils will be rising and falling at exactly the same time. This means they are 'in phase'. If they are connected in series, their voltages will add (see 'boost' in the glossary). If one coil is wound in the opposite direction, they will be 'out of phase' and their voltages will subtract (see 'buck' in the glossary). Phase angle is from 0 to 360°. The term 'in phase' means a shift of zero degrees in phase. 'out of phase' means a shift of 180° in phase.

PRIMARY; The name given to the transformer winding that is connected to the power source. It provides the energy to both magnetise the iron core and to transfer to the secondary winding(s).

REACTANCE: The world of DC has Resistance (Ohms) that controls the flow of DC current in a circuit and generates heat (Watts). In the world of AC, resistance exists but, in addition to resistance, AC circuits have Reactance. It behaves like resistance but does not generate heat. Reactance depends on the Inductance (Henrys) of an inductor or Capacitance (Farads) of a capacitor and the Frequency (Hertz) of the AC current flowing through it.   The unit of Reactance is Ohms and it behaves in a similar way to resistance in AC circuits – except that it varies with the frequency of the AC applied voltage.   Inductive Reactance increases value with frequency and Capacitive Reactance decreases as frequency rises.   The vector combination of Resistance and Inductive and Capacitive Reactance is called 'Impedance'.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6   **5**
em0060-001exp.doc   2 5 - J u l - 1 1

RECTIFICATION: AC can be changed to DC by 'rectification'. If a single diode is used, only one half of the AC waveform passes through the diode as DC and the voltage appears as 50 humps per second.   If 4 diodes are connected in a 'bridge' configuration 'full wave' rectifier, both halves of the AC waveform are rectified and the DC appears as 100 humps per second. If a transformer winding has a 'centre tapping', only 2 diodes are required to create 'full wave' rectification.   Rectification is reserved for electronic study and is not covered in this booklet.

RESISTANCE: Means the ease or difficulty that electrons have in flowing through a circuit. Glass does not conduct electricity, so it can be said that it has an extremely high resistance. Metals allow easy flow of electrons, and can be said to have a very low resistance. Every material has resistance value in OHMS.   'Kilohms' means thousands of ohms.   'Megohms' means millions of ohms.

Ohm's law: 1 volt EMF causes 1 AMP of current to flow through 1 OHM of resistance.

RMS: Means "Root Mean Square".   It is the value of the square root of the average of the sum of all the instantaneous values squared. Say the whole sine wave was divided into say 1000 separate instantaneous readings and say each reading was squared in value.   If they were all added and divided by 1000, we would have the average of all the squared values. When the square root is taken of this average of the squares, we have a close approximation of the 'effective' or the RMS value of the sine wave.

Average power of a sine wave is half the peak power $(V_p \times A_p) / 2$, thus it follows that average power equals $V_p / \sqrt{2} \times A_p / \sqrt{2}$.   It follows then that the 'effective' voltage and 'effective' current that causes average power is peak voltage / 1.414 or peak current / 1.414 (this is $\sqrt{2}$). (This equals peak value x 0.707).

Useful conversions::

RMS value = peak value x 0.707   or   AVERAGE value x 1.11

PEAK value = RMS value x 1.414   or   AVERAGE value x 1.57

AVERAGE value = peak value x 0.64   or   RMS value x 0.90

ROTOR: The rotor of a motor is the part that rotates

SECONDARY: The name given to winding(s) of a transformer that are not the 'Primary' winding.

SERIES CONNECTION: When two or more devices are connected so the current must pass from the end of one into the beginning of the next so that the same current flows through all of them, they are said to be connected 'in series.

STATOR: The stator of a motor is the part that does not rotate.

TAPPING: If a coil is wound part way (say 20 turns) and the wire is then looped from the bobbin to a connection point and then returned to the coil and the coil wound further, the coil is said to have a tapping.   Transformer coils can have as many tappings as desired to provide many voltages from the one coil. If two coils of say 50 turns are connected in series, this is the same effect as one 100 turn coil tapped at the mid point.

TRANSFORMER: This is a device where two or more coils of wire are coupled by an iron core so that the magnetic field in the iron created by one of the coils (the primary coil) induces a voltage in the other coils. The coils are not normally electrically connected to each other. Depending on the number of turns of wire on the coils, the voltage applied to the primary coil can be changed or transformed to a different voltage on the secondary coil(s). The thickness of the wire forming the coils has no effect on the voltages created. The wire thickness should be calculated to suit the current flows in and out of the transformer to avoid overheating of the wire.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6   **6**
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

VOLTAGE: This is the electrical 'pressure' that is created in a conductor when a conductor moves relative to a magnetic field to cut the lines of magnetic force. The voltage cannot cause current to flow until the circuit is closed. The voltage is dependent on the strength of the field and the speed of motion of the conductor. Voltage can be created also chemically as in a battery or by heat or light or by electric charge as in static electricity, lightning and similar. To understand voltage, it can be considered to be similar to pressure of water in a pipe. Pressure of water is present in a pipe but the flow of water (like electrical current) cannot occur until a circuit is made with pipes (like electrical wires) and until the tap is opened (like an electrical switch turned on).

VOLTS: This is the name or unit given to the potential of electricity or electrical pressure.   If one Volt of potential is applied to one Ohm of resistance, then one Amp of current flows.   If voltages are small, the unit can be millivolts or 'mV' (one thousandth of a volt). If voltages are very small, the unit can be microvolts or 'uV' (one millionth of a volt).

WATTS: When a voltage causes a current to flow through a resistance, heat is generated in the resistance. The unit of the power generated is Watts.   If powers are small, the unit can be milliwatts or 'mW' (one thousandth of a watt). If powers are very small, the unit can be microwatts or 'uW' (one millionth of a watt).   For a DC circuit, Volts x Amps = Watts.

For a purely resistive AC circuit, RMS volts x RMS amps = Watts.

For other AC circuits it is much more complicated because of the inclusion of Inductance and Capacitance. Change in the phase relationship between the voltage and the current and the vector addition of the components makes the determination of power in AC circuits more complicated. When determining power from an AC sine wave, the area of the power curve above the zero loine minus the area of the power curve below the zero line is the useful power available. The average power of a resistive sine wave power curve is exactly half of peak power. Therefore it follows that average power is: half of the multiplication of peak volts x peak amps:

Average Power $P_{av} = (V_p \times A_p) / 2 = V_p / \sqrt{2} \times A_p / \sqrt{2}$.

This means that the 'effective' voltage and current in an AC circuit is the peak value of the Sine wave divided by $\sqrt{2}$ (or multiplied by 0.707).

See also RMS in this glossary.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6   **7**
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

METERS: There are several different common types of measuring meters.

Meaning of Analogue: All analogue meters move in the same way as an electric motor turns in a magnetic field. A very fine coil of wire is held in pivots in a very strong magnetic field. If any current flows in the coil, it tries to twist in the magnetic field against springs that are trying to keep it stationary. A pointer is attached to the coil and the pointer moves on the scale to indicate a reading or measurement. Being mechanical, analogue meters can usually be repaired. Analog meters clearly show voltages changing as the pointer moves back and forth.

Meaning of Digital: Digital meters provide a numeric reading and there are no moving parts. They are normally more accurate than analogue types. Digital meters require batteries to operate and the main difficulty is that digital meters do not clearly indicate voltages that are changing because it is often impossible to follow the numbers changing rapidly. Digital meters are not easily repaired.

Analogue student meters: These are used commonly in classrooms and are individual meters with terminals. They can be either AC or DC meters and are usually made from plastic and have either one or several ranges for either Volts or Amps. They have pointers that pass over a scale, are low cost and are very good for student experiment work.

Analogue demonstration meters: These are very large meters used in a classroom for all the students to see from a great distance. They have a long and fat pointer and the large scale can often be interchanged to change the meter from AC to DC and from Volts to Amps and to change the measuring ranges.

Analogue multimeters: An analogue multimeter is one that has a pointer that passes over a scale and has many ranges and functions that can be selected by a switch on the meter. The one meter can usually read many ranges of Amps, Volts and Ohms. They are sometimes called AVO meters.

Mirror backed scale: Most analogue meters have a strip of mirror below the scale to that the user can place the pointer over the reflection of the pointer to be sure the eye is exactly vertically over the pointer. This eliminates errors due to reading the pointer at an angle (called parallax).

Digital multimeters: The kits contains a digital multimeter. They are usually accurate and have no moving parts. They often use 9 Volt batteries internally and have many AC and DC Amps, Volts and Ohms ranges. Often they can measure also Capacitance, Inductance, Temperature, Transistor Gain and Frequency.

USING METERS:

Always be careful to select AC or DC correctly. Think about the values you are measuring and always be sure to select a range higher that the readings you expect. It is always better to begin on a high range and reduce it than to start at a low range and damage the meter.   The meters are supplied with instruction sheets and connection cables with 4mm banana plug connectors.

MEASURING CAPACITANCE: The digital meter supplied in the kit can read capacitance to 20 microfarads (uF). The connection for capacitance is by a small socket on the front of the meter because usually capacitors have wires at each end of their bodies to place into the small sockets. This kit however has all 4mm banana socket connections.

ALWAYS TURN DIGITAL METERS OFF AFTER USE.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
em0060-001exp.doc   2 5 - J u l - 1 1

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Experiment list:

	EXPERIMENT	UNIT
1	Measure a resistor in ohms using ohm meter	R Ohms
2	Measure a resistor using AC volts and AC amps	R Ohms
3	Measure DC resistance of an inductor	R Ohms
4	Measure impedance of an inductor	Z Ohms
5	Measure reactance of an inductor	X_L Ohms
6	Measure inductance of an inductor	L Henrys
7	Measure resistance of a capacitor	R Ohms
8	Measure impedance of a capacitor	Z Ohms
9	Measure reactance of a capacitor	X_C Ohms
10	Measure capacitance of a capacitor	C Farads
11	Plot graphs of R, X_L and X_C relative to frequency & 'V' & 'A' Sine waves	f Hertz
12	Demonstrate AC volts and amps phase relationship in a Resistor	
13	Demonstrate AC volts and amps phase relationship in an inductor	
14	Demonstrate AC volts and amps phase relationship in a capacitor	
15	Inductors in Series and Parallel	X_L Ohms
16	Capacitors in Series and Parallel	X_C Ohms
17	Resonance, Inductor and Capacitor in Series	f Hertz
18	Resonance, Inductor and Capacitor in Parallel	f Hertz
19	Damped Oscillations	
20	Power Factor	Cosine Φ

EXPERIMENTS.

1) Measure DC resistance of a Resistor

using a multimeter (ohm meter).

Equipment required:
- 1x digital multimeter
- 1x resistor, 25 ohms.
- 2x cables with banana plugs

47Ω

DIGITAL
AMMETER

SIGNAL
GENERATOR
0.5Hz TO 50Hz

A
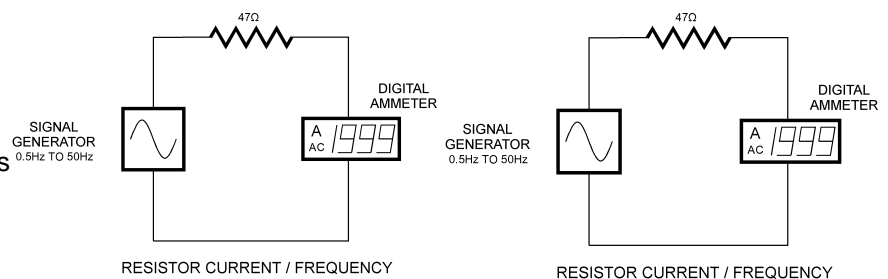AC 1999

RESISTOR CURRENT / FREQUENCY
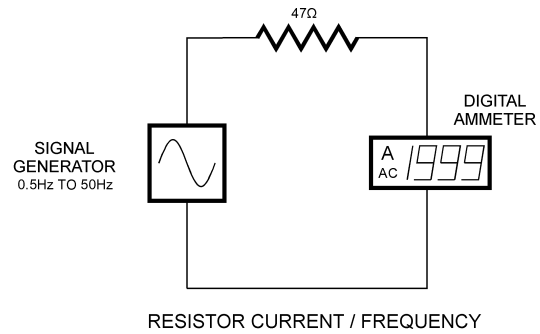
Connect the circuit as shown, select the correct range to suit the expected value and read the value of the resistance on the meter in ohms. Note how close this value is when compared to the 25 ohms marked on the resistor housing.   Calculate the percentage error.

2) Measure AC resistance using AC volts and AC amps.

Equipment required:
- 1x digital multimeter
- 1x signal generator
- 1x resistor, 25 ohms.
- 4x cables with banana plugs

47Ω

SIGNAL
GENERATOR
0.5Hz TO 50Hz

DIGITAL
AMMETER

A
AC 1999

RESISTOR CURRENT / FREQUENCY

47Ω

SIGNAL
GENERATOR
0.5Hz TO 50Hz

DIGITAL
AMMETER

A
AC 1999

RESISTOR CURRENT / FREQUENCY

Connect the first circuit as shown and set the signal generator to 50.0 Hz sine wave.

Use the AC volts range on the digital multimeter to measure and note the output voltage on the signal generator.   This voltage is the RMS value (or the effective value) of the sine wave voltage shape. Check the 'Glossary' to check the meaning of 'RMS'.   Note this voltage.

Connect the multimeter set to AC amps in series with the resistor and measure and note the AC current flowing. This is the RMS value (or the effective value) of the sine wave current shape (see later experiment and the Glossary for explanation of RMS).   Note this current.

Resistance = Volts / Amps.   Divide the RMS volts reading by the RMS amps reading and compare the value of resistance in ohms with the measured value of experiment 1).

If we could measure the instantaneous reading of the volts and the amps, we would find that the dividing of the instantaneous volts by the instantaneous amps, the instantaneous resistance value would be exactly the same.

NOTE::   The reason 50.0 Hz was chosen as the frequency to be used is that some digital meters are designed to measure accurately at around 50 to 60Hz and they are less accurate at other frequencies.

Repeat the experiment at 25.0Hz and also at 100Hz and 200 Hz. Is there a variation in your meter measurements that is caused by these different frequencies ?

Does resistance change with frequency ?

You have measured the resistance using different frequencies.

You have discovered that a change in frequency does NOT change the ohms value of the resistor.

3)   Measure the DC Resistance of an Inductor.

Equipment required:

- 1x Inductor
- 1x digital multimeter
- 2x cables with banana plugs

2H

SIGNAL
GENERATOR
0.5Hz TO 50Hz

DIGITAL
AMMETER

A
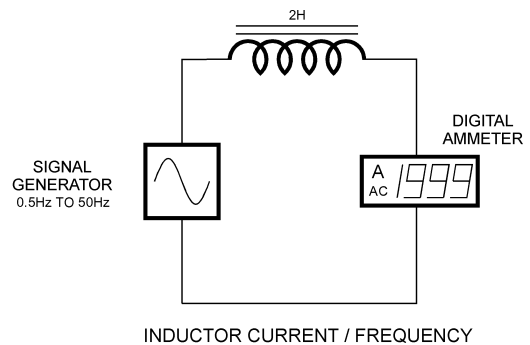AC *1999*

INDUCTOR CURRENT / FREQUENCY
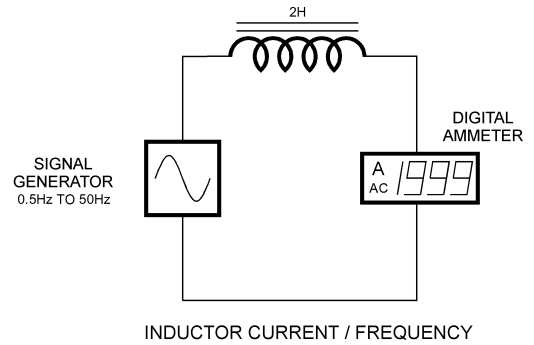
Connect the circuit as shown and read and note the resistance of the Inductor in ohms. This measurement is the resistance of the large coil of copper wire wound around the Inductor's iron core. This value will change a small amount depending on the temperature of the copper wire. The multimeter applies DC voltage to the coil to measure the resistance, so this resistance can be called the DC resistance.

Any heat generated in this wire is caused by the resistance of the wire and the current flowing through it. Power = Amps^2 x Resistance. This heat would be wasted power from the Inductor. For best efficiency for the Inductor, the resistance of the coil is kept to a minimum to keep power losses to a minimum.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

11

4) Measure the Impedance of an Inductor:

Equipment required:
- 1x Inductor
- 1x signal generator
- 1x digital multimeter
- 4x cables with banana plugs

2H

SIGNAL
GENERATOR
0.5Hz TO 50Hz

DIGITAL
AMMETER

A
AC *1999*

INDUCTOR CURRENT / FREQUENCY

Connect the circuit as shown and set the frequency of the signal generator to Sine wave and 50.0Hz.

Set the multimeter to AC volts and measure and note the voltage from the signal generator. **NOTE: The signal generator will always provide the same AC voltage at the terminals, so this voltage does not require measurement on other experiments.**

Set the multimeter to AC amps and connect it in series with the Inductor to measure the AC current flowing through the Inductor.

Calculate the Impedance (Z) by dividing the AC volts by the AC amps. Z = V / A

Notice that the Impedance (ohms) is a much higher value than the Resistance (ohms) as measured in the previous experiment.

The copper wire is the same copper wire you measured before in Ohms.   Explain why the value of 'AC resistance' in Ohms as calculated by AC volts and AC amps is much higher than the value of 'DC resistance' in Ohms as measured by the multimeter. Refer to the Glossary of Terms to find the description of 'Impedance'.

CHANGE FREQUENCY:

Now alter the frequency of the signal generator to say 25Hz and note the AC current flowing. Measure the AC current flowing and calculate the Impedance (Z ohms) as above.

Now alter the frequency to 100Hz and note the AC current flowing. Measure the AC current flowing and calculate the Impedance (Z ohms) as above.

It can be seen that the Impedance of an Inductor increases as the frequency of the AC Sine wave increases. This means that the formula for Impedance of an Inductor must include the frequency as one of the direct factors.

Repeat the experiment at frequencies of say 20Hz increments from 30Hz up to 200Hz. Calculate the Impedance at each frequency.

Using graph paper, create a graph of frequency (on the X axis) to Impedance in ohms (on the Y axis). Note that a straight line graph is the result. This means that the impedance of an inductor changes linearly and directly with frequency.

Notice that the graphed line is not pass through the Zero point. As the graph is extended to be on zero frequency, what is the displacement in ohms from the zero point ?

Does this value of ohms equal something ?

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

1 2

5) Measure the Reactance of an Inductor:

The Impedance is a combination of the DC resistance of the coil plus another type of resistance that changes with frequency. This type of 'AC resistance' is called Reactance. The symbol for reactance of an Inductor is 'X_L' and the unit is ohms. Impedance Z ohms = R ohms + X_L ohms.

Now to find the reactance of the inductor, subtract R ohms from each of your Impedance readings and plot another graph of X_L ohms against frequency.

Notice that the graph will pass through the zero point when the frequency is zero.

The difference between this graph and the impedance graph is the DC resistance value of the coil of wire that forms the Inductor.

Is this difference significant ?

WHERE DOES INDUCTIVE REACTANCE COME FROM ?   refer to the Glossary.

Explanation 1): We know from our basic DC theory that when current passes through a wire, a magnetic field is created around the wire. We know also if a magnetic field passes across a wire, a voltage is generated in the wire while the lines of magnetic force are crossing it. If the magnetic field is passing the wire quickly a higher voltage is created in the wire then when it passes slowly.

In the case of an AC voltage applied to a coil of many turns wound on an iron core, the voltage applied to the coil is rising, falling and reversing repetitively in a Sine wave shape. This means that the magnetic field in the iron core is also constantly growing and shrinking and reversing also in a Sine wave shape. This growing and shrinking of the magnetic field cuts all the turns of the coil in both the forward and reverse directions many times per second – depending on the frequency of the AC wave.

This cutting of the turns in the coil generates a voltage which, at any instant through each Sine wave, is in reverse to the applied voltage. If, for example, 10 volts AC is applied to an inductor, the reverse voltage might be equal to about 9 volts AC. This means that the resulting current flowing through the coil would be equivalent to only 1 volt being applied to the coil. This small current flowing, even though 10 volts is applied to the coil, APPEARS TO BE an increase in resistance of the coil.

Explanation 2): As an AC voltage is applied to an inductor, the current rises through the coil later, in real time, than the voltage. The voltage and the current are NOT 'in phase'. This is caused by the induced voltage in the coil caused by the current flowing through it. It causes the current to rise gradually and to LAG behind the applied voltage.

At any instant through the sine wave, the dividing of the instantaneous voltage by the instantaneous current gives an instantaneous resistance which is much higher value than the DC resistance of the coil.

This APPARENT increase of resistance is called the Reactance of the coil at that particular frequency and it will change with the frequency applied to the coil. In the case of an Inductor, the reactance (X_L ohms) increases with frequency as seen on your graph.

The Reactance depends also on the Inductance (L in Henrys) of the inductor which is dependent on the number of turns of the coil and the amount of iron in the magnetic circuit. If a coil has many turns and a large iron circuit, its Inductance is large.

6) Measure the Inductance of an Inductor:

FORMULA:

For an Inductor, **Reactance $X_L = 2\pi fL$** Where 'X_L' is the reactance in ohms, 'f' is the frequency of the Sine wave in Hertz (or cycles per second) and 'L' is the Inductance of the inductor in Henrys.

Using the figures from the different frequencies and the different values of Reactance from the previous experiment, use this formula to calculate the Inductance of the Inductor in Henrys. How close is your result to the Inductance marked on the Inductor ?

$L = X_L \, / \, 2\pi f$ Henrys

7) The resistance of a Capacitor:

The series resistance of capacitors is usually small and the value is difficult to measure. Special electronic instruments are available to measure the resistance of capacitors but they do not use first principles.

Typically, a capacitor could have a series resistance of between 0.1 ohms and 3 ohms. This resistance is an unwanted feature of capacitors because it generates heat in the capacitor as the current through it rises. The resistance value of a capacitor rises as the capacitor temperature rises and this, together with other factors, often limits the ambient temperature in which capacitors can be used and the currents that capacitors can carry.

This kit is not able to directly measure the series resistance of a capacitor, however the resistance in ohms can be seen graphically at the end of the next experiment relating to Impedance.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

1 4

8) Measure the Impedance of a Capacitor:

Equipment required:

* 1x Capacitor 5uF
* 1x signal generator
* 1x digital multimeter
* 4x cables with banana plugs
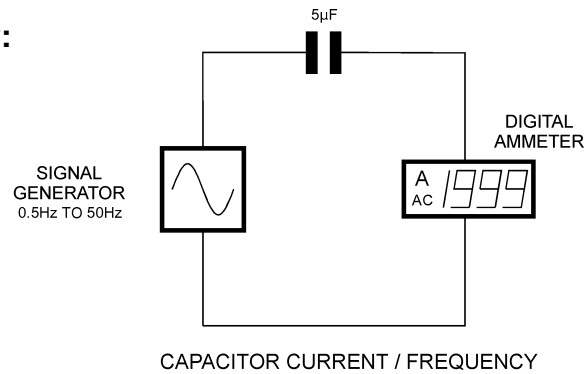
CAPACITOR CURRENT / FREQUENCY

Connect the circuit as shown and set the frequency of the signal generator to Sine wave and 50.0Hz.

Set the multimeter to AC volts and measure and note the voltage from the signal generator. **NOTE: The signal generator will always provide the same AC voltage at the terminals, so this voltage does not require measurement on other experiments.**

Set the multimeter to AC amps and connect it in series with the Capacitor to measure the AC current flowing through the Capacitor.

Calculate the Impedance (Z) by dividing the AC volts by the AC amps. Z = V / A

Notice that the Impedance (ohms) is a much higher value than the expected resistance of a capacitor as discussed in the previous experiment.

Explain why the value of 'AC resistance' in Ohms as calculated by AC volts and AC amps is much higher than the typical value of 'DC resistance' in Ohms as suggested in the previous experiment. Refer to the Glossary of Terms to find the description of 'Impedance'.

CHANGE FREQUENCY:

Now alter the frequency of the signal generator to say 25Hz and note the AC current flowing. Measure the AC current flowing and calculate the Impedance (Z ohms) as above.

Now alter the frequency to 100Hz and note the AC current flowing. Measure the AC current flowing and calculate the Impedance (Z ohms) as above.

It can be seen that the Impedance of a Capacitor decreases as the frequency of the AC Sine wave increases. This means that the formula for Impedance of a capacitor must include the frequency as one of the inverse factors.

Repeat the experiment at frequencies of say 20Hz increments from 30Hz up to 200Hz. Calculate the Impedance at each frequency.

Using graph paper, create a graph of frequency (on the X axis) to Impedance in ohms (on the Y axis). Note that a straight line graph is the result. This means that the impedance of a capacitor changes linearly and inversely with frequency.

Notice that the graphed line is not pass through the Zero point. As the graph is extended to be on zero frequency, what is the displacement in ohms from the zero point ?

Does this value of ohms equal something ?

9) Measure the Reactance of a Capacitor:

The Impedance is a combination of the DC resistance of the capacitor plus another type of resistance that changes with frequency. This type of 'AC resistance' is called Reactance. The symbol for reactance of a Capacitor is 'Xc' and the unit is ohms. Impedance Z ohms = R ohms + Xc ohms.

Now to find the reactance of the capacitor, subtract R ohms from each of your Impedance readings and plot another graph of Xc ohms against frequency.

Notice that the graph will pass through the zero point when the frequency is zero.

The difference between this graph and the impedance graph is the DC resistance value of the capacitor.

Is this difference significant ?

WHERE DOES CAPACITIVE REACTANCE COME FROM ?   refer to the Glossary.

We know from our basic DC theory that a capacitor consists of metal plates with an insulation material between them. Current cannot pass directly from one metal plate to the other. When a voltage is applied to the capacitor plates, a current passes to the plates to create a CHARGE equal to the applied voltage. This DC current is momentary as the plates become charged.

When a AC voltage is applied to a capacitor, since the applied voltage is rising and falling and reversing many times per second, the charging current is passing into and out of the plates repetitively thus causing an AC current to flow. The plates are constantly charging and reversing their charge attempting to make the voltage between them equal the applied voltage at any instant.

In the case of a Resistor, the resistance at any instant of the Sine wave is exactly the instantaneous voltage divided by the instantaneous current flowing and the current flows at exactly the time as the voltage is applied. Therefore the AC resistance of a pure resistor is, at any instant inside the Sine wave, the same as the DC resistance of the resistor.

In the case of a Capacitor, since the voltage on the plates is created by the charging current flowing into them, the current flowing into a capacitor is, in real time, ahead of the voltage across the plates. The voltage and the current Sine waves are not rising and falling at the same time. In other words, they are not 'in phase'.

If the instantaneous value of the voltage is divided by the instantaneous value of the current, the instantaneous value of the 'equivalent resistance' is not the same as a resistor. In addition, the faster the applied voltage changes, the faster the current passes in and out of the capacitor plates. This faster current flow equates to a larger current flowing. If a larger current flows, this means that the 'equivalent resistance' is falling and there APPEARS TO BE a reduction of the resistance of the capacitor.

This equivalent resistance is called Capacitive Reactance and has the symbol **'Xc'** with a unit of **Ohms.** It reduces in value with an increase in frequency of the applied voltage as seen on your graphs.

The Reactance depends also on the Capacitance (C in Farads) of the capacitor which is dependent on the area of the metal plates and the thickness of the insulation between them. If a capacitor has large plates and a very thin insulation between them, its Capacitance is large.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6   **1 6**
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

10)   Measure the Capacitance of a Capacitor:

FORMULA:

For a Capacitor,   **Reactance Xc = 1 / 2πfC**   Where 'Xc' is the reactance in ohms, 'f' is the frequency of the Sine wave in Hertz (or cycles per second) and 'C' is the Capacitance of the capacitor in Farads.

Using the figures from the different frequencies and the different values of Reactance from the previous experiment, use this formula to calculate the Capacitance of the Capacitor in Farads. How close is your result to the Capacitance in microfarads (uF) marked on the Capacitor ?

## C = 1 / (2πf x Xc) Farads

11) Graphs:

Using data from previous experiments, plot graphs of the following:

> Resistance of a pure Resistor against Frequency
> Reactance in Ohms of an Inductor against Frequency
> Reactance in Ohms of a Capacitor against Frequency
> Sine wave of voltage and current for a resistor on AC.   The Current and Voltage are in phase. Calculate several instantaneous values of resistance at different places along the sine wave graph (volts / amps).
> Sine wave of voltage and current for an Inductor on AC.   The Current lags the Voltage by 90°.   Then, using several instantaneous values of Inductive Reactance ('AC resistance') at different places along the sine wave graph (volts / amps), plot the AC Reactance.
> Sine wave of voltage and current for a Capacitor on AC. The Current leads the Voltage by 90°.   Then, using several instantaneous values of Capacitive Reactance ('AC resistance') at different places along the sine wave graph (volts / amps), plot the AC Reactance.

12) Demonstrate the AC Volts and Amps relationship for a Resistor:

 Equipment required:
* 1x Resistor
* 1x signal generator
* 1x centre zero voltmeter
* 1x centre zero ammeter
* 5x cables with banana plugs

AMMETER
DC 300mA - 0 - 300mA

SIGNAL
GENERATOR
SET TO 0.5Hz

47Ω

VOLTMETER
DC 10V - 0 - 10V
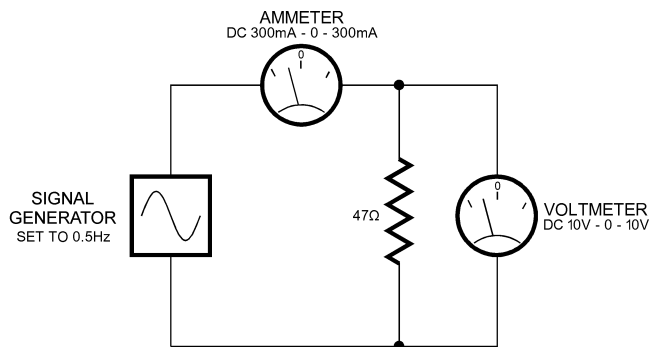
CURRENT & VOLTAGE IN PHASE

Connect circuit as shown above.   Set the Signal Generator to a frequency of about 1 Hz. Adjust the frequency so the meters swing at a suitable rate to follow their movements by eye.

Observe the sweeping of the meters.

Notice that the amps swing follows the volts swing exactly. This means the amps and the volts are changing value 'in phase'.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6   **1 7**
em0060-001exp.doc   2 5 - J u l - 1 1

13) Demonstrate the AC Volts and Amps relationship for an Inductor:

Equipment required:

- 1x Inductor
- 1x signal generator
- 1x centre zero voltmeter
- 1x centre zero ammeter
- 5x cables with banana plugs

Connect circuit as shown above. Set the Signal Generator to a frequency of about 1 Hz. Adjust the frequency so the meters swing at a suitable rate to follow their movements by eye.
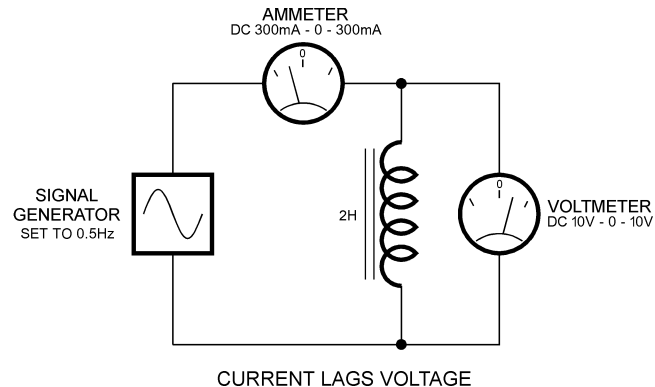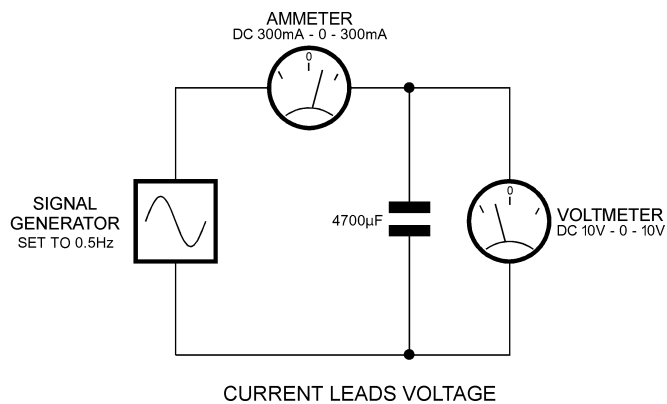
Observe the sweeping of the meters.

Notice that the amps swing LAGS behind the volts swing. This means the amps and the volts are both changing value, but are NOT 'in phase'. Look carefully and notice that as the volts reach maximum, the current is at minimum. This displacement in real time is a 90° displacement on the Sine wave.

14) Demonstrate the AC Volts and Amps relationship for a Capacitor:

Equipment required:

- 1x Capacitor
- 1x signal generator
- 1x centre zero voltmeter
- 1x centre zero ammeter
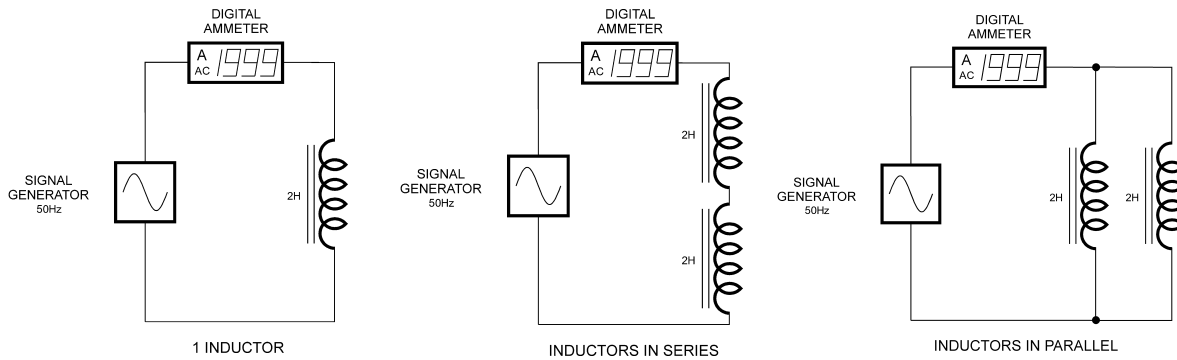- 5x cables with banana plugs

Connect circuit as shown above. Set the Signal Generator to a frequency of about 1 Hz. Adjust the frequency so the meters swing at a suitable rate to follow their movements by eye.

Observe the sweeping of the meters.

Notice that the amps swing LEADS ahead of the volts swing. This means the amps and the volts are both changing value, but are NOT 'in phase'. Look carefully and notice that as the current reaches maximum, the voltage is at minimum. This displacement in real time is a 90° displacement on the Sine wave.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1
18

15) Inductors in series and parallel:

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

2H

1 INDUCTOR

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

2H

2H

INDUCTORS IN SERIES

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

2H   2H

INDUCTORS IN PARALLEL

Equipment: 2x Inductors   1x signal generator   1x digital multimeter   4x cables with banana plugs. Connect circuit with one inductor as shown above.   Set the Signal Generator to a frequency of 50 Hz and measure the current flowing.

Refer to earlier data or re-calculate the Inductive reactance in ohms by subtracting the DC resistance from the Impedance.   Note the reactance in ohms.
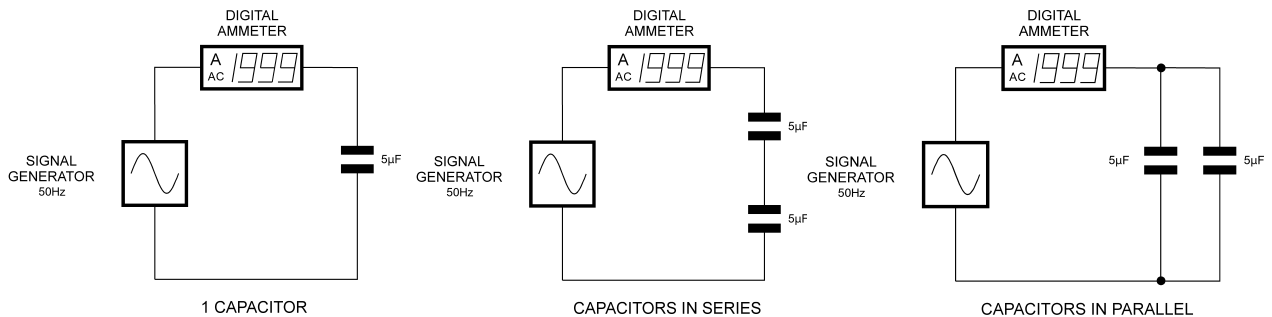
Now connect the 2 Inductors in series as shown above and again measure the current flowing. Now calculate the new Reactance.

Now connect the 2 Inductors in parallel and again calculate the new Reactance.

Since $X_L = 2\pi fL,$ if the Reactance has changed, then the inductance also has changed by the same proportion because the frequency and pi are constant.

What is the rule you have discovered regarding Inductors in series and in parallel ?

16) Capacitors in series and parallel:

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

5µF

1 CAPACITOR

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

5µF

5µF

CAPACITORS IN SERIES

DIGITAL AMMETER
A AC /999

SIGNAL GENERATOR 50Hz

5µF   5µF

CAPACITORS IN PARALLEL

Equipment: 2x Capacitors 1x signal generator 1x digital multimeter   4x cables with banana plugs Connect circuit with one capacitor as shown above.   Set the Signal Generator to a frequency of 50 Hz and measure the current flowing.

Refer to earlier data or re-calculate the Capacitive reactance in ohms by subtracting the DC resistance from the Impedance.   Note the reactance in ohms.

Now connect the 2 Capacitors in series as shown above and again measure the current flowing. Now calculate the new Reactance.

Now connect the 2 Capacitors in parallel and again calculate the new Reactance.

Since $X_C = 1 / 2\pi fC,$ if the Reactance has changed, then the capacitance also has changed INVERSELY by the same proportion because the frequency and pi are constant.

What is the rule you have discovered regarding Capacitors in series and in parallel ?

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17) Resonance: Inductor and Capacitor in series:

Equipment required:

- 1x Inductor
- 1x Capacitor
- 1x Resistor
- 1x signal generator
- 1x digital multimeter
- 6x cables with banana plugs
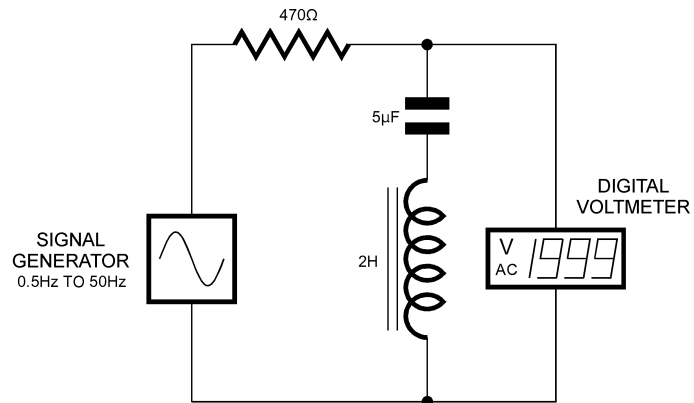
SERIES RESONANCE

Connect circuit with a resistor in series with one inductor and one capacitor as shown above. Set the Signal Generator to a low frequency of say 10 Hz.

We know that as the frequency rises, the Inductive reactance increases and the Capacitive Reactance decreases.

We know also that the current in an inductor is 90° lagging the voltage and the current in a capacitor is leading the voltage by 90°. This means that the two currents must be 180° out of phase (opposing each other). So, it follows that when the two Reactances are the same and since both currents are opposing one another, the current flowing through the two in series should be ZERO and the AC voltage across the pair in series should be maximum.

The frequency at which this occurs is called the **'Resonant Frequency'** of the series circuit.

Monitor the voltage across the series pair and gradually increase the frequency. Note the frequency where the voltage is maximum. Increase the frequency further and notice the voltage. Readjust the frequency to obtain the maximum voltage.

Calculate the Reactance of the capacitor and the Reactance of the Inductor at this frequency.

What do you notice about the results ?

QUESTION: What is the purpose of the series resistor in this circuit.

CLUE: What would the voltage reading be at all times if the resistor was not there ?

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
61-65 McClure St. Thornbury. 3071 Melbourne. Australia
Tel: 61 (0)3 9497 2555   Fax: 61 (0)3 9497 2166
em0060-001exp.doc   25-Jul-11

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18) Resonance: Inductor and Capacitor in parallel:

Equipment required:
- 1x Inductor
- 1x Capacitor
- 1x Resistor
- 1x signal generator
- 1x digital multimeter
- 6x cables with banana plugs

470Ω

SIGNAL
GENERATOR
0.5Hz TO 50Hz

5µF   2H

DIGITAL
VOLTMETER

V
AC *1999*

PARALLEL RESONANCE
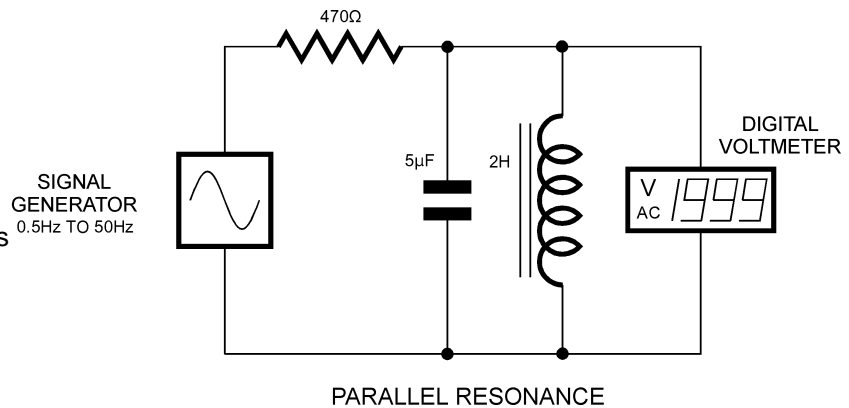
Connect circuit with a resistor in series with one inductor and one capacitor in parallel as shown above.   Set the Signal Generator to a low frequency of say 10 Hz.

We know that as the frequency rises, the Inductive reactance increases and the Capacitive Reactance decreases.

We know also that the current in an inductor is 90° lagging the voltage and the current in a capacitor is leading the voltage by 90°. This means that the two currents must be 180° out of phase (opposing each other). So, it follows that when the two Reactances are the same and since both currents are opposing one another, the current flowing through the two in parallel should be MAXIMUM and the AC voltage across the pair in series should be minimum.

The frequency at which this occurs is called the **'Resonant Frequency'** of the parallel circuit.

Monitor the voltage across the parallel pair and gradually increase the frequency. Note the frequency where the voltage is minimum. Increase the frequency further and notice the voltage. Readjust the frequency to obtain the minimum voltage.

Calculate the Reactance of the capacitor and the Reactance of the Inductor at this frequency.

**What do you notice about the results ?**

QUESTION: What is the purpose of the series resistor in this circuit.

CLUE: What current would the signal generator need to supply if the resistor was not there ?

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
em0060-001exp.doc   25-Jul-11

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19) Damped Oscillations:

Equipment required:

- 1x Inductor
- 1x Capacitor
- 1x Switch
- 1x DC power supply
- 1x centre zero voltmeter
- 7x cables with banana plugs

CLOSE MOMENTARILY

POWER SUPPLY — 10V.DC.

4700µ   2H

DAMPED OSCILLATION
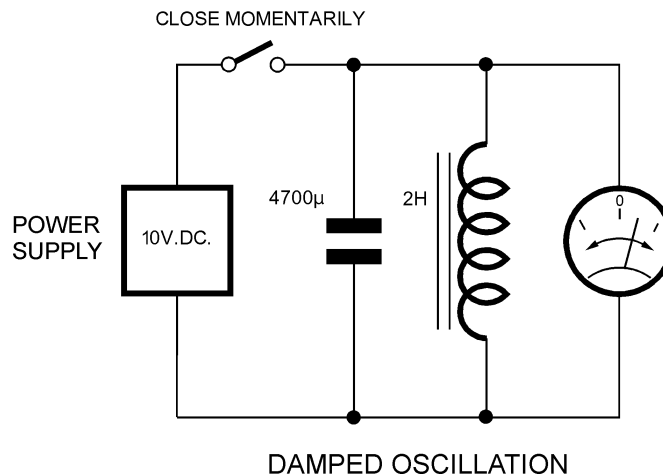
Connect circuit with a DC power supply set to about 10V.DC.   Polarity does not matter.

When the switch is closed momentarily, the Capacitor will charge rapidly to 10 volts and a DC current will begin to build up through the Inductor.

When the switch is opened again, the capacitor will discharge into the inductor's coil and the inductor's magnetic field will grow in the iron circuit and then will collapse as the capacitor discharges. As the field collapses in the iron circuit, the magnetic lines of force cut the turns in the coil and a voltage is induced in the opposite direction. This reverse voltage will have enough energy to partially charge the capacitor in the reverse direction.

The newly charged capacitor will discharge again and this oscillating action will show on the centre zero voltmeter as the oscillations reduce rapidly to zero.

QUESTIONS:

1)   What causes the rapid stopping of the oscillations when the switch is opened ?

2)   How long would the oscillations continue if the resistance of the capacitor and the inductor and the connections totaled zero ohms ?

We know that as the frequency rises, the Inductive reactance increases and the Capacitive Reactance decreases.

We know also that the current in an inductor is 90° lagging the voltage and the current in a capacitor is leading the voltage by 90°. This means that the two currents must be 180° out of phase (opposing each other). So, it follows that when the two Reactances are the same and since both currents are opposing one another, the current flowing through the two in parallel should be MAXIMUM and the AC voltage across the pair in series should be minimum.

The frequency at which this occurs is called the **'Resonant Frequency'** of the parallel circuit.

Monitor the voltage across the parallel pair and gradually increase the frequency. Note the frequency where the voltage is minimum. Increase the frequency further and notice the voltage. Readjust the frequency to obtain the minimum voltage.

Calculate the Reactance of the capacitor and the Reactance of the Inductor at this frequency.

What do you notice about the results ?

QUESTION: What is the purpose of the series resistor in this circuit.

CLUE: What current would the signal generator need to supply if the resistor was not there ?

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
em0060-001exp.doc   2 5 - J u l - 1 1
2 2

20) Power Factor:

Equipment required:
- 1x Inductor
- 1x Capacitor
- 1x Switch
- 1x Signal Generator
- 1x centre zero voltmeter
- 1x centre zero ammeter
- 8x cables with banana plugs

POWER FACTOR CORRECTION
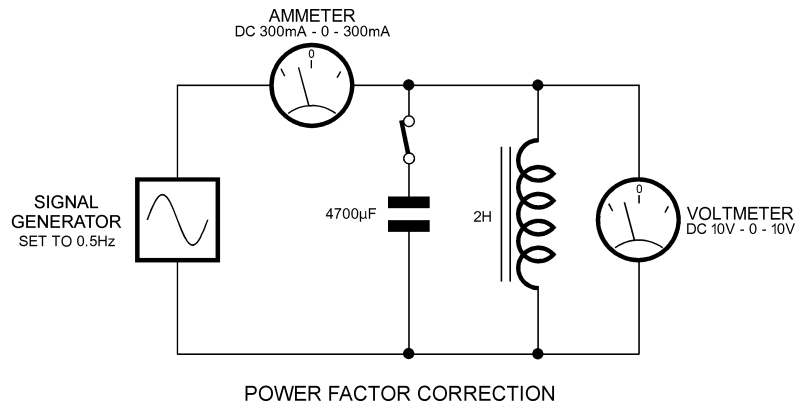
Connect circuit as shown above. The switch permits the addition of the capacitor to be connected in parallel with the inductor. The two centre zero meters are measuring the circuit current and the voltage across the load and also, if the frequency is very low, permit observation of the phase relationship between the current and the voltage..

WHAT IS POWER FACTOR ?

We know from basic theory that in a DC circuit, the multiplication of Volts x Amps = Watts of power. The same is true in an AC circuit where the load is purely resistance.

In AC circuits, the multiplication of Volts and Amps is not called Watts, it is called **Volt Amps**.

When an AC circuit has either Inductance or Capacitance, the power calculation is very different. Power Factor is a number that is mathematically the Cosine of the angle of Lead or Lag in an AC circuit. If the multiplication of volts and amps in an AC circuit is multiplied by the Power Factor, the actual usable power is the result. Formula is: Volt Amps x Cos (lead or lag) = Watts of power.

If the angle is 90o the resultant power is zero because Cos 90°=0. If the angle is zero, the resultant power is maximum because Cos 0°=1

Therefore it can be seen that to get the best power from a motor or other AC device, the smallest angle of lead or lag gives the best efficiency from the device. EXAMPLE: If an AC motor has a power output of say 1000 watts and runs on a voltage of 100 volts, the current should be 10 amps for best efficiency. BUT if the angle of lag is say 45°, the current will be 14.1 amps. You will be buying 14.1 amps from the power company and using 14.1 amp sized wiring etc but you will be receiving only 10 amps worth of power from the motor.

To generate usable power in an AC circuit, it is very important that the instantaneous volts and the instantaneous amps multiply together to form the largest positive going Sine wave of power. On your graph of current through an inductor, draw a power curve (also a sine wave) which is V x A at any point along the sine wave.

Draw the power curve on your graph of AC passing through a resistor. Note that when the voltage and current are in phase, the resultant power is a Sine wave that is always on the positive side of the Sine wave's zero line.

Now draw the power curve for your Inductor. When the current lags or leads the voltage by exactly 90°, the power curve as seen on your graphs is equal on both the positive and negative sides of the zero line, therefore the average power is zero.

In a perfect Inductor, the DC resistance of the coil is zero and the iron circuit does not generate heat and the angle of lag is exactly 90°. Because power is zero, there is no heat generated by the perfect Inductor. The same theory holds for the perfect Capacitor.

In the case of the electric motor mentioned above, it is an inductive device, so to try to improve the Power factor (reduce the angle of lag) a capacitor is added in parallel to the inductive motor winding. This can be simulated in the circuit at the start of this experiment.

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
em0060-001exp.doc   2 5 - J u l - 1 1

2 3

POWER FACTOR Cont'd:

Set the Signal Generator to about 1.5 Hz and observe the lag between the current flowing and the voltage applied to the inductor.

Now close the switch and add the capacitor into the circuit.

Notice that the current is not lagging the voltage to the same amount. This means that the leading angle of the capacitor has, to some degree, compensated the angle of lag and it is reduced from about 90° to a much smaller angle.

This technique of 'Power factor Correction' is used very widely in industry to improve the efficiency of inductive machines like electric motors. By reducing the current drawn by perhaps hundreds of motors, large savings of many thousands of dollars can be made on industrial electricity bills.

Designed and Manufactured in Australia

I N D U S T R I A L   E Q U I P M E N T   &   C O N T R O L   P T Y . L T D .
6 1 - 6 5   M c C l u r e   S t .   T h o r n b u r y .   3 0 7 1   M e l b o u r n e .   A u s t r a l i a
T e l :   6 1   (0) 3   9 4 9 7   2 5 5 5   F a x :   6 1   (0) 3   9 4 9 7   2 1 6 6
e m 0 0 6 0 - 0 0 1 e x p . d o c   2 5 - J u l - 1 1

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