Unit UEEENE102A

SOLVE PROBLEMS IN
LOW VOLTAGE
A.C. CIRCUITS

BOOK 1 of 2
**Introduction:**
- Introduce yourself.
- Welcome to Electrical Trades TAFE NSW TAFE.
- TAFE NSW is part of SWSI Institute.
- Check enrolment forms.
- Discuss the requirement to carry TAFE.

**General Induction:**
- Discuss location of:
  - Toilets
  - Building exits
  - Evacuation area
  - Fire extinguishers
  - First aid
  - Emergency Stop buttons (class room induction)

- Refer to the STUDENT CALENDAR (in front of book) and discuss the following:
  - Use for important dates, exams, holidays etc.
  - Schedule exam make-up dates etc. (only in consultation with the class teacher)

- Refer to the STUDENT CONTACTS page (in front of book) and discuss the following:
  - Head Teachers phone number and office number
  - Teachers phone number and office number
  - College support unit contacts and phone number
  - Other college phone numbers

- Refer to the EVACUATION PLAN and discuss the following:
  - Fire and Bomb threat procedures
  - The evacuation procedure
  - The requirement to check the roll at the evacuation area

- Refer to the COLLEGE MAP and discuss the following:
  - Car parking
  - Canteen & operating hours
  - Phone (in canteen – free for local calls only)
  - Student Association (in canteen area)
  - Library & operating hours
  - Main Office

- Refer to the MINIMUM STUDENT REQUIREMENTS page and discuss the following:
  - Each item listed in the document
  - Break times and punctuality
  - Emphasise employer correspondence for non-adherence
  - Always have required PPE. ie: clear safety glasses, correct footwear etc.
  - Always carry required resources eg: pens, calculators, drawing instruments & standards
Class Orientation

- Refer to the USEFUL LINKS page and discuss the following:
  - Available websites and services
  - Login procedures for varying services and sites
  - Recording of students DEC User ID and Password
  - Procedure for downloading Australian Standards
  - Accessing Moodle courses

- Refer to the EQUATION SHEET and discuss the following:
  - Every new student workbook has an equation sheet
  - Only new / clean equation sheets will be permitted in exams
  - Not all exams require the use of an equation sheet

- Refer to the WORK PERFORMANCE EVIDENCE page and discuss the following:
  - A broad overview of workplace training
  - The need to collect evidence whilst at work
  - Skills Tracker recording – Login details etc.
  - Skills Tracker orientation will be done during the year
  - You cannot course complete without adequate work performance evidence

- Refer to the COURSE OUTLINE and discuss the following:
  - Four year apprenticeship (in general)
  - Three years at TAFE, fourth year in the workplace
  - The IMPORTANCE of evidence collection for Workplace Performance (Skills-tracker)
  - Options for failed units and repeat classes
  - Failing a unit twice

- Refer to the UNIT GUIDE and discuss the following:
  - Prerequisites, and the possible need to repeat a unit or part thereof before advancing
  - Student Assessment Guidelines and signing of guidelines for each unit
  - Consequences for Cheating
  - Contacting the class teacher for missed exams
  - Explain the SAGs assessment table and the timing / weighting of exams
  - Successful completion of a unit is only achieved when a student shows sufficient Essential Knowledge & Associated Skills (EKAS) contained within the unit, whereby;
    - Essential Knowledge is determined by the KS associated with the unit, and
    - Skills are demonstrated by consistent performance across a representative range of contexts.

  NOTE: Evidence of skills may be collected in a number of ways. Examples include:
  - Skills-tracker portfolios
  - Workbook UNIT portfolios
  - In class simulated workplace activities, documented in the class roll by the teacher
  - A combination of all of the above.

Tour of Campus: - For new classes, visit required locations listed above
Electrical Trades Section - TAFE NSW

1. **SHOES / PPE**  
   Fully enclosed leather-top shoes must be worn at all times in all parts of the building. **Definitely no thongs or sandals.**

2. **ATTIRE**  
   Clean tidy clothing is required. Tops are required to have sleeves. **No singlet-style tops.**

3. **EYES / PPE**  
   **Clear, non-tinted safety glasses** must be provided by the student and worn where required e.g. workshop classes.

4. **BOOKS**  
   Each student must have his/her own text, tutorial and workbooks as well as any required accessories e.g. pens, drawing instruments, calculator, AS3000 rule book.

5. **ATTENDANCE**  
   Students are expected to be punctual and attend classes for the entire duration. In the event of not being able to attend a class or classes, the student should inform the class teacher and their employer.  
   Non-attendances will result in employers being notified.

6. **ASSESSMENTS**  
   Students that miss exams for ANY reason must where possible contact their class teacher beforehand. Acceptable supporting evidence as to why the exam was missed MUST be provided. e.g. doctor certificate for illness. Refer to the ‘student assessment guidelines’ for further important information.
   - ‘SCHOOLIES’ is not an acceptable reason to miss exams.
   - Cheating and Plagiarism will not be tolerated

7. **SMOKING**  
   Smoking is not permitted on the College grounds at any time. Please make your way to the College entrance on Banks Road.

8. **EATING**  
   The consumption of food or drink is not permitted in any part of any building within the College (with the exception of the College Canteen).

9. **MOBILE PHONES**  
   **Mobile phones are to be turned off** prior to entering any classroom, workshop or wiring room. Mobile phones are not to be accessed during class.

10. **DISCIPLINE**  
    Students must be familiar with, and adhere to, the Code of Conduct which is printed in the Student Handbook that is available from the main office.
Stage 1: This list does not contain all equations in the course and transposition may be required.

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<thead>
<tr>
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<th>C</th>
<th>D</th>
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<tbody>
<tr>
<td>1</td>
<td>( Q = It )</td>
<td>( F = ma )</td>
<td>( W = Pt )</td>
<td>( W = Fs )</td>
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<tr>
<td>2</td>
<td>( V = IR )</td>
<td>( I = \frac{V}{R} )</td>
<td>( R = \frac{V}{I} )</td>
<td>( P = \frac{2\pi nT}{60} )</td>
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<tr>
<td>3</td>
<td>( P = VI )</td>
<td>( P = I^2R )</td>
<td>( P = \frac{V^2}{R} )</td>
<td>( \eta% = \frac{\text{output}}{\text{input}} \times 100 )</td>
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<tr>
<td>4</td>
<td>( R = \frac{\rho l}{A} )</td>
<td>( R_2 = \frac{R_1 A_1 l_2}{A_2 l_1} )</td>
<td>( R_n = R_c(1 + \alpha \Delta t) )</td>
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<td>5</td>
<td>( V_T = V_1 + V_2 + V_3 )</td>
<td>( R_T = R_1 + R_2 + R_3 )</td>
<td>( I_T = I_1 = I_2 = I_3 )</td>
<td>( V_1 = V_T \frac{R_1}{R_1 + R_2} )</td>
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<td>6</td>
<td>( V_T = V_1 = V_2 = V_3 )</td>
<td>( \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} )</td>
<td>( I_T = I_1 + I_2 + I_3 )</td>
<td>( I_2 = I_T \frac{R_1}{R_1 + R_2} )</td>
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<tr>
<td>7</td>
<td>( C = \frac{Q}{V} )</td>
<td>( C = \frac{A \varepsilon_\varepsilon_r}{d} )</td>
<td>( \tau = RC )</td>
<td>( C_T = C_1 + C_2 + C_3 )</td>
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<tr>
<td>8</td>
<td>( L = N \frac{\Delta \Phi}{\Delta I} )</td>
<td>( L = \frac{N^2 S}{2} )</td>
<td>( \tau = \frac{L}{R} )</td>
<td>( V = N \frac{\Delta \Phi}{\Delta t} )</td>
</tr>
<tr>
<td>9</td>
<td>( e = Blv )</td>
<td>( F = Bil )</td>
<td>( F_m = IN )</td>
<td>( B = \frac{\Phi}{A} )</td>
</tr>
<tr>
<td>10</td>
<td>( E_g = k\Phi n )</td>
<td>( T = k\Phi l )</td>
<td>( T = Fr )</td>
<td>( H = \frac{F_m}{l} )</td>
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Symbols obtained from AS1046
Stage 2: This list does not contain all equations in the course and transposition may be required.

Stage 1: equations are also used during stage 2

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<td>11</td>
<td>$V_{ave} = 0.637V_{max}$</td>
<td>$V_{RMS} = 0.707V_{max}$</td>
<td>$v = V_{max} \sin \theta$</td>
<td>$V_L = \sqrt{3}V_p$</td>
<td>$f = \frac{nP}{120}$</td>
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<tr>
<td>12</td>
<td>$I_{ave} = 0.637I_{max}$</td>
<td>$I_{RMS} = 0.707I_{max}$</td>
<td>$i = I_{max} \sin \theta$</td>
<td>$I_L = \sqrt{3}I_p$</td>
<td>$t = \frac{1}{f}$</td>
</tr>
<tr>
<td>13</td>
<td>$I = \frac{V}{Z}$</td>
<td>$V = IZ$</td>
<td>$Z = \frac{V}{I}$</td>
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<td>14</td>
<td>$Z = \sqrt{R^2 + X^2}$</td>
<td>$Z = \sqrt{R^2 + (X_L - X_C)^2}$</td>
<td>$X_L = 2\pi f L$</td>
<td>$X_C = \frac{1}{2\pi f C}$</td>
<td>$\cos \theta = \frac{R}{Z}$</td>
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<tr>
<td>15</td>
<td>$P = VI \cos \theta$</td>
<td>$S = VI$</td>
<td>$Q = VI \sin \theta$</td>
<td>$P = \sqrt{S^2 - Q^2}$</td>
<td>$\cos \theta = \frac{P}{S}$</td>
</tr>
<tr>
<td>16</td>
<td>$P = \sqrt{3}V_L I_L \cos \theta$</td>
<td>$S = \sqrt{3}V_L I_L$</td>
<td>$Q = \sqrt{3}V_L I_L \sin \theta$</td>
<td>$\tan \theta = \sqrt{3} \frac{W_1 - W_2}{W_1 + W_2}$</td>
<td>$\theta = \cos^{-1} \lambda$</td>
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<tr>
<td>17</td>
<td>$V' = 4.44\phi f N$</td>
<td>$V_1 = \frac{N_1}{N_2}$</td>
<td>$I_2 = \frac{N_1}{N_2}$</td>
<td>$V_{reg%} = \frac{(V_{NL} - V_{FL})}{V_{FL}} \times \frac{100}{1}$</td>
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<tr>
<td>18</td>
<td>$N_{syn} = \frac{120f}{P}$</td>
<td>$f_r = \frac{S% \times f}{100}$</td>
<td>$S% = \frac{(n_{syn} - n)}{n_{syn}} \times \frac{100}{1}$</td>
<td>$V_{reg%} = \frac{(V_{NL} - V_{FL})}{V_{NL}} \times \frac{100}{1}$</td>
<td>$T = k\phi Ia$</td>
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<td>19</td>
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<td>20</td>
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<td></td>
<td></td>
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<td>$P = \frac{2\pi nT}{60}$</td>
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**Stage 2a:** This list does not contain all equations in the course and transposition may be required.

**Stage 1:** equations are also used during stage 2

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<td>21</td>
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<tr>
<td>22</td>
<td>( V_T = E_g - (I R_i) )</td>
<td>( E = \frac{F}{A} )</td>
<td>( E = \frac{l}{d^2} )</td>
<td>( E = \frac{l}{d^2} \times \cos \theta )</td>
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<tr>
<td>23</td>
<td>( Q_c = P(\tan \theta_1 - \tan \theta_2) )</td>
<td>( X_c = R(\tan \theta_1 - \tan \theta_2) )</td>
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**Stage 3:** This list does not contain all equations in the course and transposition may be required.

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<tr>
<td>25</td>
<td>( V_p Y = 57.7% V_p \Delta )</td>
<td>( I_p Y = 57.7% I_p \Delta )</td>
<td>( I_{motor\ st} = \left( \frac{%TAP}{100} \right) \times I_{DOL} )</td>
<td>( I_{line\ st} = \left( \frac{%TAP}{100} \right)^2 \times I_{DOL} )</td>
</tr>
<tr>
<td>26</td>
<td>( I_{ST} = \frac{1}{3} \times I_{DOL} )</td>
<td>( T_{ST} = \frac{1}{3} \times T_{DOL} )</td>
<td>( V_{st} = \left( \frac{%TAP}{100} \right) \times V_{DOL} )</td>
<td></td>
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<tr>
<td>27</td>
<td>( I_{ST} = \left( \frac{V_{st}}{V} \right) \times I_{DOL} )</td>
<td>( T_{ST} = \left( \frac{V_{st}}{V} \right)^2 \times T_{DOL} )</td>
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<td>28</td>
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Unit Guide – Summary

FULL unit guides can be accessed online at www.training.gov.au
The following information is summarised and is intended to provide a broad overview only.

Unit:
UEENEEG102A Solve problems in low voltage a.c. circuits

Unit Descriptor
This unit covers ascertaining correct operation of single and three phase a.c. circuits and solving circuit problems as they apply to servicing, fault finding, installation and compliance work functions. It encompasses safe working practices, multiphase circuit arrangements, issues related to protection, power factor and MEN systems and solutions to circuit problems derived from calculated and measured parameters.

Pre-Requisites
Pre-requisites are units of study that must be completed prior to commencing a new unit of study. That is, you must pass subject ‘X’ before you are allowed to commence subject ‘Y’. In some instances, pre-requisite units may be studied concurrently with new units of study.

Pre-requisites for this unit of study are:

- UEEENEE101A Apply Occupational Health and Safety regulations, codes and practices in the workplace
- UEEENEE104A Solve problems in d.c circuits
- UEEENEEG101A Solve problems in electromagnetic devices and related circuits
Unit Guide – Assessment

**Student Assessment Guidelines – (SAG’s)**

Assessment is an important part of learning at TAFE NSW.

TAFE NSW provides comprehensive information for students regarding assessment. A copy of ‘Every Student’s Guide to Assessment in TAFE NSW’ can be obtained by visiting:


The following information provided in this workbook is to assist you in your understanding of the assessment process, by providing an overview of assessment for this unit. Any questions regarding assessment can be addressed by your class teacher.

**Course:** National Course Code: UEE30811

**Qualification and name:** Certificate III in Electrotechnology Electrician

**TAFE NSW course number:** 20222. Version: 1

**Requirements to receive the qualification:**

To achieve UEE30811 Certificate III in Electrotechnology, learners are required to complete all units from the core and elective units to a weight of 140 points. Core and elective units are shown in the ‘Course Outline’ contained in the preceding pages of this workbook.

**Recognition:** If you have completed other relevant training you may be eligible to have units of competency from previous training counted towards completion for this course. Talk to your teacher or head teacher if you think you may be eligible for recognition for units previously completed.

**Learner Support:** Students who require support to meet their learning goals should discuss their options by talking to their teacher or Teacher/Consultant for students with a disability.

**Assessment Results:** Results will be made available to you by your class teacher after each assessment event. Results may also be viewed online (final unit results only) by visiting TAFE ‘eServices’. See the ‘Useful Links’ on the ‘student contacts’ page in the front of this workbook for further information on TAFE eServices. Concerns you may have about your assessment results should be addressed to your class teacher within 3 weeks of receiving a result.
Unit Guide – Assessment

Required skills and knowledge
This describes the essential skills and knowledge and their level, required for this unit.
Evidence shall show that knowledge has been acquired of safe working practices, rationale and solving problems in the relevant unit. The knowledge and skills shall be contextualised to current industry standards, technologies and practices.

View the section title page in your class workbook or the complete unit guide for a full list of the fundamentals covered by each topic within this unit.
Below is a list indicating the content areas to be covered by the required skills and knowledge specification for this unit:

Note: Topics may not be delivered in the order indicated by the full unit guide.
Additional information pertinent to your learning may also be included during unit delivery.

KS01-EG102A – Alternating current power circuits

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<th>CONTENT</th>
<th>TOPIC NUMBER AS LISTED IN THE FULL UNIT GUIDE</th>
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<td>Series R-L-C Circuits</td>
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<td>Section 8  Book 1</td>
<td>Parallel AC Circuits</td>
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<td>Section 8  Book 2</td>
<td>Star-Delta Interconnected Systems</td>
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<td>Appendix A</td>
<td>Fault Loop Impedance</td>
<td>T15</td>
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Note: Fault Loop Impedance also covered in UEENEEG107A: Electrical Apparatus & Circuits Section 7 (T7) KS01 – EG107A
Absence from a class assessment:

All students are expected to sit class assessments at the normal scheduled time.

If due to ill health or other unforeseen and acceptable circumstances you are not able to attend a scheduled class test, it is **your responsibility** to make contact with your class teacher or the section head teacher and inform them of your reason for missing the assessment.

**NOTE:** This contact must be made, prior to, but certainly no later than 24 hours after the scheduled assessment.

Failure to contact the class teacher or section head teacher within the specified time will be taken as your withdrawal from the assessment and a **zero mark** will be recorded.

‘Schoolies’ is not an acceptable reason to miss an assessment. Zero marks will be recorded.

Your Class Teachers Name: __________________________________
Your Class Teachers Phone No: ________________________________
Or Head Teachers No:

Workplace Health and Safety (WHS):

The laws protecting the Health and Safety of people at work apply to students who attend TAFE Colleges, either part time or full time. These laws emphasise the need to take reasonable steps to eliminate or control risk at work (this includes a TAFE College). TAFE NSW has the responsibility for the control, and where possible, the elimination of health and safety risk at the college. This includes bullying and harassment. You are encouraged to help in eliminating hazards by reporting to your teacher or other College staff, anything that you think may be a risk to you or other people.

Your teacher will encourage you to assist in hazard identification and elimination, and to devise control measures for any risks to yourself and other people that may arise during practical exercises. The WHS Act 2011 requires that teachers and students take reasonable steps to control and monitor risk in the classroom, workshop or workplace.

*Individuals failing to observe and follow ALL Workplace Health and Safety requirements in any part of the college, not limited to but including, hall-ways, class rooms, laboratories, wiring rooms and workshops will be promptly removed for their own safety and for the safety of others. Breaches will be recorded on your TAFE record.*
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AC PRINCIPLES

PURPOSE:

To develop an understanding of the characteristics of alternating voltage and current waveforms and how they are generated.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Describe what is meant by the terms alternating voltage and alternating current.
- Explain how a sinusoidal voltage is generated in a single turn coil rotated in a uniform magnetic field.
- Draw an alternating waveform and identify the -
  - positive and negative amplitudes
  - positive half-cycle and negative half-cycle
  - period
  - peak to peak value
  - peak value.
- Define the terms ‘period’, ‘maximum value’, ‘peak-to-peak value’, ‘instantaneous value’, ‘average value’ and ‘root-mean-square (rms) value’ in relation to a sinusoidal waveform.
- Calculate the instantaneous value of induced voltage of a generated sinusoidal waveform.
- Calculate the root-mean-square (rms) value and frequency of a sinusoidal waveform from values of peak voltage and period.

REFERENCES:

Pages 159-162, 165-170.
1. **REVISION - DIRECT CURRENT**

When a unidirectional emf, known as a DC voltage, is applied to a resistive circuit, a flow of electrons is established. This electron flow takes place in one direction only, from the negative terminal of the supply to the positive terminal. See figure 1.

![Figure 1](image1.png)

The electron flow is known as current flow and by convention is assumed to flow from the positive terminal of the supply to the negative terminal. As this current flows in one direction only, it is known as direct current and the voltage driving it is known as a DC voltage.

2. **ALTERNATING CURRENT**

An alternating current of electricity is defined as an electric current, which alternately reverses its direction in a circuit in a periodic manner. This means that an alternating current changes its direction around the circuit at regular intervals of time, usually much less than one second.

An alternating current, considered in terms of electron theory, is the transfer of electrons first one way and then the other through the circuit, changing direction regularly at short intervals, see figure 2.

![Figure 2](image2.png)

The number of electrons that pass any given cross-section of the circuit will vary from instant to instant. This must mean that the speed of the electrons is increased and then decreased, then increased in the reverse direction and then decreased, again reversed and so on. The force which produces this motion of electrons is the alternating electromotive force applied to the circuit, or as it is known the AC voltage.
3. WAVEFORMS

A waveform is a graphical representation used to show the changes that occur in a voltage or current over a period of time. When waveforms are drawn certain conventions are followed -

- the horizontal axis represents ________________
- the height of the waveform represents the ________________ of either voltage or current over a period of time
- all alternating waveforms have both ________________ and ________________ portions.

Figure 3 shows a selection of various waveforms.

![Waveform Diagram]

Figure 3

Note - all alternating waveforms have both positive and negative values or portions.
4. ALTERNATING WAVEFORM QUANTITIES

A number of different terms are used to describe the characteristics of alternating waveforms. These terms include -

- **positive half-cycle** - the portion of the waveform above zero
- **negative half-cycle** - the portion of the waveform below zero
- **peak value** ($V_M$ or $I_M$) - the maximum value of the waveform which occurs twice, positive maximum and negative maximum
- **peak to peak value** ($V_{pp}$ or $I_{pp}$) - the magnitude of the wave from the maximum positive value to the maximum negative value.
- **period** ($T$) - the time taken to complete one cycle, measured in seconds
- **cycle** - one complete set of positive and negative values
- **frequency** ($f$) - the number of cycles completed in one second, measured in hertz (Hz)

Figure 4 illustrates the application of terms used in conjunction with alternating waveforms.

![Figure 4](image-url)
If the period (also known as the periodic time) of the waveform is known, the frequency may be determined -

\[
\text{where:} \quad T = \text{period, in seconds} \\
\text{ } \quad f = \text{frequency, in hertz}
\]

Conversely, if the frequency of a waveform is known, the period may be determined -

\[
\text{where:} \quad f = \text{frequency, in hertz} \\
\text{ } \quad T = \text{period, in seconds}
\]

**Example: 1**

For the waveform shown in figure 5 determine the:

(a) peak to peak value
(b) maximum value
(c) period
(d) frequency

![Figure 5](image-url)
5. THE SINE WAVE

Modern alternators are designed to generate an electromotive force (emf) having a sinusoidal waveform, that is, the emf generated obeys the sine wave law.

The main advantages of a sinusoidal waveform are -

- it is the only waveform that can be transformed in a transformer and retain the same shape
- some measuring instruments only operate satisfactorily with sine waves of emf or current.

A sine wave is produced when a conductor moves in a circular path within a magnetic field, producing a varying electromotive force (emf). This is illustrated in figure 6.

![Figure 6](image)

The relationship between the instantaneous value of the emf and the angle that the conductor has moved is represented by the equation -

\[ e = \frac{BLv}{\theta} \]

where:

- \( e \) = the instantaneous value of the induced emf, in volts
- \( B \) = the flux density, in teslas
- \( l \) = the effective length of conductor within the magnetic field, in metres
- \( v \) = the velocity at which the conductor travels, in metres per second
- \( \theta \) = the angular displacement from the reference point, in degrees
The value of induced voltage or circuit current at any instant in time can be calculated given the maximum value of the sine wave and the phase angle -

\[
\begin{align*}
\text{where:} & \quad v \text{ and } i \text{ are instantaneous values of voltage and current} \\
& \quad V_M \text{ and } I_M \text{ represent the maximum values of voltage and current} \\
& \quad \theta = \text{the phase angle, in degrees}
\end{align*}
\]

**Example: 2**

A sine wave has a maximum value of 12A. Calculate the instantaneous current values at angles of -

(a) 30°
(b) 225°.

(a) 
(b) 

**Example: 3**

A sine wave has a maximum value of 150V. Calculate the instantaneous voltage values at angles of -

(a) 40°
(b) 135°
(c) 210°
(d) 300°

(a) 
(b) 
(c) 
(d)
6. **RMS VALUE OF A SINE WAVE**

The representative value used to specify the strength of the sine wave is called the -

- ________________________________ value (rms value), or
- ______________________________ value, or
- ______________________________ value.

Unless otherwise specified, AC quantities are always stated in terms of the rms value.

The rms value of an alternating current produces the same heating effect as an equal value of DC voltage or current.

For a sinusoidal waveform -

where: $V$ and $I = \text{the rms value of voltage and current, in volts and amperes}$

$V_M$ and $I_M = \text{the maximum value of voltage and current, in volts and amperes}$

**Example: 4**

A sinusoidal voltage has a maximum value of 600V. Determine the rms value of the waveform.

**Example 8:**

A sinusoidal current has an rms value of 15A. Determine the maximum value of the waveform.
7. **AVERAGE VALUE OF AN ALTERNATING WAVEFORM**

As shown in figure 7, the area under the positive half of the wave is equal to the area under the negative half of the wave.

![Figure 7](image)

Therefore the average value of voltage or current **over one full cycle** is -

- \[
\frac{1}{2} V_M + \frac{1}{2} I_M
\]

The average value of an alternating voltage or current **over half a cycle** is not zero, and depends on the type of waveform.

In the case of a sine wave the average value for one half cycle is equal to 0.637 times the maximum value.

where: \(V_{AV}\) and \(I_{AV}\) = average values of voltage and current, in volts and amperes

\(V_M\) and \(I_M\) = maximum values of voltage and current, in volts and amperes.

Average values are more applicable in circuits involving the conversion of AC to DC, than in everyday AC circuits. That is, the average value of a waveform may be used to determine the output voltage from a rectifier.
8. FORM FACTOR and CREST FACTOR

The form factor of a wave of alternating current or voltage is defined as the ratio of the rms value to the average value.

For a sinusoidal waveform -

\[
\text{Form Factor} = \frac{\text{rms value}}{\text{average value}} = \frac{0.707}{0.637} = 1.11
\]

For the purpose of this course, form factor will only be considered when converting average values to rms values in determining fundamental emf equations for the alternator and transformer.

The crest factor of an alternating emf must be taken into consideration when dealing with the quality of insulation of conductors and equipment.

The crest factor of a wave of alternating current or voltage is defined as the ratio of the maximum value to the rms value.

For a sinusoidal waveform -

\[
\text{Crest Factor} = \frac{\text{maximum value}}{\text{rms value}} = \frac{1}{0.707} = 1.414
\]
AC PRINCIPLES

PURPOSE:

This practical assignment will be used to introduce the use of the cathode ray oscilloscope (CRO) and the characteristics of the sine wave.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Use the CRO to measure periodic time, peak to peak and maximum values of a sine wave.
- Determine the frequency of a sine wave using a CRO and the equation $f = \frac{1}{T}$.
- Determine the ratio of $\frac{V_{pp}}{V_{max}}$ for a sine wave.
- Compare the voltage values as determined from the display on the CRO with the value indicated by an AC voltmeter.

EQUIPMENT:

☐ 1 x variable AC supply
☐ 1 x cathode ray oscilloscope
☐ 1 x 1000Ω, 10W wire wound resistor
☐ 1 x AC voltmeter (AVO8 multimeter)
☐ 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.
The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. CRO SET UP

1. Connect the circuit shown in figure 1.

![Circuit Diagram](image)

Figure 1

2. Switch on the CRO. Do not turn on the power supply.
3. Select the SWEEP TIME/DIV for a sweep time of 5ms/Div.
4. Set the TRIGGERING to AUTO by pulling the SYNCH LEVEL adjuster out.
5. Select the TRIGGER SOURCE selector to CHANNEL 1.
6. Set channel 1 INPUT SELECTOR to AC.
7. Select channel 1 on the MODE selector switch.
8. Select 5V/Div on the channel 1 VOLTS/DIV selector switch.
9. Centralise the following controls -
   (a) INTENSITY
   (b) HORIZONTAL POSITION
   (c) VERTICAL POSITION for both channels.
10. Adjust FOCUS for a clear, sharp picture.
11. Ensure the VOLTS/DIV and SWEEP TIME controls are set to CAL.
12. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

13. Ensure the trace is adjusted EXACTLY to the horizontal centre of the screen.
2. **VOLTAGE MEASUREMENTS**

1. Turn on the AC power supply, close the circuit switch and adjust the power supply until the waveform displayed has a value of 10Vpp. (Note - this is 2 divisions at 5V/Div.)

2. In order to become familiar with the CR0 controls, carry out the following steps and observe the effect on the display:—
   (a) Move the horizontal position control from side to side, then back to centre.
   (b) Move the vertical position control up and down, then back to centre.
   (c) Move the Volts/Div selector one way then the other, then back to 5V/Div.
   (d) Move the sweep time selector one way then the other, then back to 5mS/Div.
   (e) Adjust the trigger level control one way then the other, then stabilise the display again.

3. Open the circuit switch, then ensure that the CR0 is adjusted for 5mS/Div and 5V/Div. Adjust so that the line is exactly on the horizontal centre of the screen.

4. Close the circuit switch and adjust the power supply to give an output of 10Vpp. Measure Vmax and the periodic time and record the values in Table 1.

<table>
<thead>
<tr>
<th>Peak to Peak Voltage Vpp</th>
<th>Maximum Voltage Vmax</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>10V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Readjust the supply to measure and record the values of Vmax and the periodic time for Vpp of 20V and 30V respectively.

6. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
3. RMS VALUE OF A SINE WAVE

1. Connect the circuit as shown in figure 2. Use an AC voltmeter set to the 30V AC voltage range.

![Circuit Diagram](image)

Figure 2

2. Turn on the power supply, close the circuit switch and adjust the supply until the voltmeter indicates 5V.

   Note: The voltmeter measures the rms value of voltage.

3. Using the CRO measure the peak to peak value of the voltage waveform and the periodic time. Record the values in table 2.

<table>
<thead>
<tr>
<th>Voltmeter Reading</th>
<th>CRO</th>
<th>Calculations to be Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vrms</td>
<td>Vpp</td>
<td>T</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td></td>
<td></td>
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<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Do not proceed until the teacher checks your results and completes the progress table.

   Progress Table 3

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

5. Switch off the supply, then disconnect the circuit.

6. Return all equipment to its proper place, safely and carefully.
4. OBSERVATIONS:

1. The peak to peak value of a waveform should be twice the maximum value. Using the values recorded in table 1, determine if this was the case for the sine wave examined.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

2. From table 1, what was the value of the periodic time for the sine wave? Using this value determine the frequency of the sine wave.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

3. When using the CRO, why is it necessary to adjust the trace to exactly the vertical centre of the screen?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

4. Complete table 2 by calculating Vmax, the ratio of Vrms + Vmax and the frequency using readings taken from the CRO.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
5. Explain the purpose of the voltage selector control on the CRO.

6. Explain why the maximum value of voltage, as displayed on the CRO, was greater than the voltage indicated by the voltmeter.

7. Based on the results of this practical and the results recorded in table 2, how large is the rms value of a sine wave compared to the maximum value?
A.C. Principles

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The value of AC voltage shown on the name plate of an appliance is the:
   (a) average value
   (b) peak value
   (c) instantaneous value
   (d) r.m.s. value

2. The value of AC voltage that has the same heating effect as the equivalent value of DC voltage is the:
   (a) rms value.
   (b) peak value.
   (c) average value.
   (d) peak to peak value.

3. For one complete cycle of an AC supply, the current flow:
   (a) will remain constant in magnitude.
   (b) will flow in one direction only.
   (c) will flow in one direction then reverses direction.
   (d) reaches a maximum in one direction then falls to zero.

4. The standard unit of frequency is the:
   (a) Hertz (Hz)
   (b) Volt (V)
   (c) period (T)
   (d) cycle per second (CPS)
5. The term *frequency* of an AC supply is defined as the:
   (a) number of cycles completed in one minute.
   (b) number of cycles completed in one second.
   (c) time required to complete one cycle.
   (d) the amount of a cycle completed in one second.

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. The standard ___(a)___ of the AC supply in Australia is 50Hz, and this means that there are 50 ___(b)___.

7. ______ will continuously change its direction of current flow with time.

8. With reference to a sinusoidal waveform, define what is meant by the following terms:
   (a) period;
   (b) form factor;
   (c) peak value;
   (d) average value;
   (e) peak to peak value; and
   (f) instantaneous value.

9. The ratio of the peak value of voltage to the rms value of voltage is known as the ___(a)___, and for a sinusoidal waveform has a value of ___(b)___.

10. The ratio of the rms value of voltage to the average value of voltage is known as the ___(a)___, and for a sinusoidal waveform has a value of ___(b)___.

**SECTION B**

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

11. A sinusoidal wave has a maximum value of 340 volts. Determine the instantaneous value of voltage at angles of:
    (a) $45^0$ (240V)
    (b) $105^0$ (328.4V)
    (c) $260^0$ (334.8V)
    (d) $330^0$ (-170V)

12. A sinusoidal wave has a frequency of 400 Hz. Determine the period for this frequency.
    (2.5mS)
13. A sinusoidal wave has a maximum value of 500 volts. For this wave, determine:
   (a) the rms value; (353.6V)
   (b) the peak to peak value; (1000V)
   (c) the average value. (318.5V)

14. Determine the frequencies for the following periodic times:
   (a) 0.02 seconds (50Hz)
   (b) 0.0833 seconds (12Hz)
   (c) 1 millisecond (1000Hz)
   (d) 0.05 milliseconds (20kHz)

The following questions refers to Table 1 and the graph shown on page 4. Add page 4 to your submitted tutorial solution.

15. Complete the sin value row of Table 1 by determining the sine values for the angles as shown.

16. If the maximum voltage of the waveform is 120V, complete the voltage value row of Table 1 by determining the instantaneous values of voltage for the angles shown using your calculated sin values.

17. Carefully plot the results on the graph supplied, completing your waveform using either French curves or a flexicurve. Do not finish your waveform in freehand!

18. On your completed waveform, label the following:
   (a) the peak value,
   (b) the peak to peak value,
   (c) the periodic time,

19. Draw and label straight lines where you would expect to find the:
   (a) the rms value,
   (b) the average value.

20. From your waveform, determine the value of voltage at:
   (a) 20° (41V)
   (b) 100° (118V)
   (c) 220° (-77V)
   (d) 140° (77V)
## Table 1

<table>
<thead>
<tr>
<th>Degrees</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>135</th>
<th>150</th>
<th>165</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin Value</td>
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<tr>
<td>Voltage Value</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Degrees</th>
<th>195</th>
<th>210</th>
<th>225</th>
<th>240</th>
<th>255</th>
<th>270</th>
<th>285</th>
<th>300</th>
<th>315</th>
<th>330</th>
<th>345</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin Value</td>
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<td>Voltage Value</td>
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</tbody>
</table>

### A.C. Principles

### Tutorial 1

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Miller Electrical  
page 20  

Applied Electrical Technology A.C.  
LSEG302A (9080B)  
Ver 1 / December 2008
SINUSOIDAL WAVEFORMS

PURPOSE:

To develop an understanding of AC circuit phase relationships and the application of phasor diagrams.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:
- Determine the phase relationships between two or more sinusoidal waveforms from a given diagram or measurements.
- Describe the meaning of the terms -
  - in-phase
  - out-of-phase
  - phase angle
  - angle of lead
  - angle of lag.
- Determine the phase angle or angles between two or more alternating quantities from a given diagram of sinusoidal waveforms.
- Define the term phasor.
- Draw the phasor representation of sinusoidal quantities.

REFERENCES:

Pages 170-172.
1. PHASE RELATIONSHIPS

If two alternating voltages or currents pass through zero together and follow the same cycle of changes, they are said to be -

- ___________________________, or in step with each other.

Figure 1 shows two sinusoidal voltage waves $V_1$ and $V_2$ respectively, in phase with each other. It should be noted from this diagram that these voltages are always of the same polarity and pass through corresponding instantaneous values, for example, zero and maximum, respectively at the same time.

![Figure 1](image1.png)

If two voltages have the same frequency but do not pass through corresponding instantaneous values at the same time, they are said to be -

- ___________________________ or out of step with each other, see figure 2.

![Figure 2](image2.png)

The time separation between the two waves is measured as an angle ($\theta$) which is known by either of two names -

- the ___________________________, or
- the ___________________________.

---

**Sinusoidal Waveforms**

Section 2

---

*Applied Electrical Technology A.C.*
*LSEGG302A (9080B)*
*Ver 1 / December 2008*
The conditions of "in phase" and "out of phase" also apply to an alternating voltage and an alternating current of the same frequency.

Figure 3 shows an alternating current which is out of phase with an alternating voltage wave of the same frequency.

Since time is measured along the horizontal axis, the current wave is said to _______ behind the voltage wave because the current passes through its zero and maximum values after the voltage. Normally, this would be stated -

- ____________________________________________________.

The time interval between the two waves is called the "phase difference" between the voltage and current. Phase difference is usually expressed in terms of electrical time degrees. This difference is called -

- an ____________________________ when referring to a lagging quantity, and
- an ____________________________ when speaking of a leading quantity.

In figure 4 the ______________________________________________________________.

---

Figure 3

Figure 4
In alternating current theory, the voltage is taken to be the standard in determining the phase relationship with the current. Hence -

- in figure 3, the current _______________________________
- in figure 4, the current _______________________________

When the phase difference between two alternating voltages or currents is 180 electrical degrees, as in figure 5, they are said to be in direct opposition to each other.

![Figure 5](image)

**2. PHASOR DIAGRAMS**

A simpler method of displaying AC quantities is the phasor diagram. The information displayed in the wave diagrams of figures 1 through 5 can be shown using a phasor diagram, in which -

- voltages and currents are represented by phasors
- phasor rotation is always considered to be anti-clockwise.

A phasor is a straight line in which its -

- length represents the magnitude of the waveform, usually the rms value, and must be drawn to scale
- direction represents its phase relationship.

![Figure 6](image)
The following rules should be followed when drawing phasors diagrams -

(a) phasors are always drawn with respect to a horizontal reference
(b) a reference is chosen which is a quantity common to all parts of the circuit, for example, current in a series circuit and voltage in a parallel circuit
(c) phasors must always be drawn to scale, generally representing the rms value
(d) voltage phasors are always drawn with an open arrowhead
(e) current phasors are always drawn with a closed arrowhead
(f) phasor rotation is always anti-clockwise

Figure 7 shows a sinusoidal voltage with an rms value of 50V and a sinusoidal current of 2A. The current lags the voltage by a phase angle of 45º. The same information is shown in the phasor diagram of figure 8.

Example: 1

Draw the phasor diagram for the circuit of figure 9, in which the current $I_1$ lags the supply voltage by 30º and the current $I_2$ leads the supply voltage by 50º.
**Example: 2**

Draw the phasor diagram for the two voltages shown in figure 10. The rms values for the two waveforms are $V_1 = 100V$ and $V_2 = 50V$.

![Figure 10](image1.png)

**Example: 3**

Draw the phasor diagram for the two voltages shown in figure 11. The rms values for the two waveforms are $V_1 = 100V$ and $V_2 = 65V$.

![Figure 11](image2.png)
**Example: 4**

Draw the phasor diagram for the waveforms shown in figure 12. The voltage wave has a maximum value of 100V and the current a maximum value of 42.4A

![Figure 12](image-url)
**Example: 5**

Draw the phasor diagram for the waveforms shown in figure 13. The voltage wave has a maximum value of 340V and the current a maximum value of 20A.

![Figure 13](image-url)
Example: 6
Draw the phasor diagram for the two voltages shown in figure 14. The two voltages are equal and have rms values 200V.

![Figure 14](image)

Example: 7
Describe the phase relationships between voltage and current for the currents shown in the phasor diagram of figure 15.

![Figure 15](image)

Current $I_1$ - 

Current $I_2$ - 

Current $I_3$ - 
3. DETERMINING PHASE DIFFERENCE

Phase difference is the time displacement in electrical degrees between two waveforms that operate at the same frequency. A complete cycle of a waveform takes 360°. Once a waveform has passed through 360°, it repeats itself.

To determine the angle of phase difference between two waveforms two values need to be known -
- the period of the waveforms
- time displacement between the waveforms.

Figure 16 shows voltage and current waveforms that are out of phase. To determine the angle of phase displacement, apply the following equation -

\[ \text{time difference} = \frac{\text{5mS}}{15mS} \]

Example: 8
Two sinusoidal waveforms with a frequency of 50Hz are displayed on a CRO. If the time displacement between the waveforms is measured to be 2.3mS, determine the angle of phase difference between the two waveforms.
SINUSOIDAL WAVEFORMS

PURPOSE:

This practical assignment will be used to examine the phase relationship between voltage and current in three basic AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:
- Use the CRO to examine the phase relationship between voltage and current in an AC circuit.
- State whether a circuit current leads, lags or is in phase with the supply voltage of an AC circuit.
- Use the CRO to measure the phase difference between two alternating quantities.
- Draw the phasor diagram for AC circuits.
- Compare the voltage values as determined from the display on the CRO with the value indicated by an AC voltmeter.

EQUIPMENT:

- 1 x fixed, single phase AC supply
- 1 x signal generator
- 1 x cathode ray oscilloscope + leads
- 1 x R-L-C panel
- 1 x digital multimeter
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. RESISTIVE CIRCUIT

1. Connect the circuit shown in figure 1.

![Circuit Diagram]

CRO Settings
- Channel 1 = 10V/div
- Channel 2 = 0.05V/div
- Sweep Time = 5mS/div

2. Switch on the CRO and select the SWEEP TIME/DIV for a sweep time of 5mS/Dev.

3. Do not turn on the power supply.

4. Ensure the CRO VOLTS/DIV and SWEEP TIME controls are set to CAL.

5. Ensure the CRO traces are adjusted EXACTLY to the vertical centre of the screen.

6. Do not proceed until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

7. Turn on the AC supply - two sinusoidal waveforms should appear on the screen of the CRO.
   - Channel 1 - the supply voltage
   - Channel 2 - the circuit current.

8. Using the digital multimeter measure the rms value of the supply voltage and record in table 1.

9. Using the CRO measure the peak to peak values of the supply voltage and circuit current. Record in table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRO</td>
</tr>
<tr>
<td>Supply Voltage Vpp</td>
</tr>
</tbody>
</table>

10. Neatly sketch the two waveforms on the diagram of figure 2.
11. What is the phase relationship between the circuit current and the supply voltage?

The circuit current - ________________________________

2. INDUCTIVE CIRCUIT

1. Connect the circuit shown in figure 3.
2. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 2**

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

3. Turn on the AC supply - two sinusoidal waveforms should appear on the screen of the CRO.
   - Channel 1 - the supply voltage
   - Channel 2 - the circuit current.

4. Using the digital multimeter measure the rms value of the supply voltage and record in table 2.

5. Using the CRO measure the peak to peak values of the supply voltage and circuit current. Record in table 2.

   **Table 2**

<table>
<thead>
<tr>
<th>Supply Voltage Vpp</th>
<th>Circuit Current Ipp</th>
<th>Supply Voltage Vrms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Neatly sketch the two waveforms on the diagram of figure 4.

   **Figure 4**

7. What is the phase relationship between the circuit current and the supply voltage?

   The circuit current - __________________________
8. Using the CRO measure the periodic time of the supply voltage waveform.

   Periodic time = ______________________

9. Change the SWEEP TIME setting on the CRO to 2mS/div.
10. Using the CRO measure the time separation between the supply voltage and circuit current.

   Time separation = ______________________

11. Determine the phase angle between the supply voltage and current.

   Phase angle = \( \frac{\text{Time Separation}}{\text{Periodic Time}} \times 360^\circ = \) ______________________

12. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 3**
   
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

3. **CAPACITIVE CIRCUIT**

1. Connect the circuit as shown in figure 5.

   ![Circuit Diagram]

   **Figure 5**

   **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 4**
   
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
2. Switch on the signal generator and adjust to give a supply voltage of 0.5V, as indicated on the digital multimeter. Two sinusoidal waveforms should appear on the screen of the CRO.
   Channel 1 - the supply voltage  Channel 2 - the circuit current.

3. Using the CRO measure the peak to peak values of the supply voltage and circuit current. Record in table 3.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRO</td>
</tr>
<tr>
<td>Supply Voltage Vpp</td>
</tr>
<tr>
<td>0.5V</td>
</tr>
</tbody>
</table>

4. Neatly sketch the two waveforms on the diagram of figure 6.

5. What is the phase relationship between the circuit current and the supply voltage?
   The circuit current - ___________________________

6. Using the CRO measure the periodic time of the supply voltage waveform.
   Periodic time = _______________________

7. Change the SWEEP TIME setting on the CRO to 0.2mS/div.
8. Using the CRO measure the time separation between the supply voltage and circuit current,

\[ \text{Time separation} = \text{___________________________} \]

9. Determine the phase angle between the supply voltage and current.

\[ \text{Phase angle} = \frac{\text{Time Separation}}{\text{Periodic Time}} \times 360 \]

\[ \text{Phase angle} = \text{___________________________} \]

10. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 5**
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

11. Switch off the supply, then disconnect the circuit.

12. Return all equipment to its proper place, safely and carefully.

4. **OBSERVATIONS:**

   1. What is the phase relationship between voltage and current in an AC resistive circuit.

      __________________________________________________________
      __________________________________________________________
      __________________________________________________________

   2. What effect does inductance have on the phase relationship between voltage and current in an AC circuit?

      __________________________________________________________
      __________________________________________________________
      __________________________________________________________

   3. What effect does capacitance have on the phase relationship between voltage and current in an AC circuit?

      __________________________________________________________
      __________________________________________________________
      __________________________________________________________
4. Using the peak to peak voltages measured from the CRO, in procedures 1, 2 and 3, calculate the rms value of supply voltage for each circuit.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

5. Compare the calculated values of supply voltage from question 4, with the voltages measured using the digital multimeter. Based on your results, what value of a waveform is measured by a multimeter when set to AC ranges?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

6. Draw the phasor diagram for the circuit of figure 1.
7. Draw the phasor diagram for the circuit of figure 2.

8. Draw the phasor diagram for the circuit of figure 3.
Sinusoidal Waveforms

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. When measuring the phase difference with a CRO., the CRO.
   (a) must be able to show two waveforms.
   (b) needs to have a high sensitivity.
   (c) time base must be re-calibrated.
   (d) must be set to DC input.

2. Phasors are quantities which vary in:
   (a) magnitude and time only
   (b) magnitude and direction only
   (c) magnitude, direction and time
   (d) direction only

3. If one waveform leads another, then it will pass through _____ and maximum values _____ the other waveform.
   (a) zero; before
   (b) zero; after
   (c) zero; simultaneously with

4. In practice, when representing AC quantities by phasor diagram, the phasors are usually drawn to scale to represent:
   (a) rms values
   (b) instantaneous values
   (c) maximum values
   (d) average values

5. The term *phase angle* is defined as the:
(a) angle used to determine the instantaneous value of voltage or current.
(b) the angular displacement between two waveforms of the same frequency.
(c) the angular displacement between two waveforms of different frequencies.
(d) the number of degrees into a cycle where the peak value is reached.

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. Two waveshapes are said to be ______ when they pass through their zero points or peak values simultaneously.

7. To represent a voltage quantity in a phasor diagram, an arrow with a/an ___(a)___ head is used, whilst a current quantity is represented by an arrow with a/an ___(b)___ head. Draw an example of a voltage phasor representing 100V (1.0mm = 2.5V), and an example of a current phasor representing 24A (1.0mm = 0.3A).

8. If two waveshapes do not pass through the same changes at the same time, they are said to be ______

9. To determine the frequency of a sinewave from a CRO., you would read the ___(a)___ axis and use the the setting of the ___(b)___ switch.

10. Briefly describe how you could determine:
    (a) if two waveshapes are in phase;
    (b) if two waveshapes are out of phase;
    (c) if out of phase, which one leads or lags the other.

11. Phasors are normally drawn to scale to represent _____ quantities.

12. The relationship between frequency and periodic time states that frequency is ___(a)___ to periodic time. This can be written mathematically as ___(b)___

13. Phasors are said to rotate in a/an _____ direction.

14. Briefly describe how you could prove that the rms value of a sinewave is 0.707 of the peak peak value of a sinewave. Accompany your answer with a clearly labelled diagram.
SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

15. A display of a sinusoidal waveform on a CRO is 2.8 divisions high and 8 divisions long. If the VOLTS/DIV is set to 10V, and the SWEEP TIME/DIV is set to 1mS, determine:
   (a) the peak value of voltage (28V)
   (b) the expected rms value of voltage (19.8V)
   (c) the frequency of the waveform (125Hz)

16. Two sinusoidal waves with a frequency of 50 Hz are displayed on a CRO. If the horizontal displacement between the waveforms is measured to be 3.5mS, determine the phase angle between the two waveshapes (63°)

17. Draw a phasor diagram to represent a voltage V1 of 240V and a second voltage V2 of 180V, such that V1 leads V2 by 50°. Use a scale of 1.0mm = 2.0V, and make V1 the reference.

18. Draw a phasor to represent a current I1 of 2.5A, a second current I2 of 3A and a third current I3 of 1.75A, drawn to scale of 1.0mm = 25mA. I1 leads I2 by 30°, and I3 lags I2 by 45°. Use I2 as your reference phasor.

19. The diagram of figure 1 represents two sinusoidal waveforms of the same frequency. If the VOLTS/DIV switch is set to 10V, and the SWEEP TIME/DIV switch is set to 5mS, determine:
   (a) the peak values of voltage for waveforms V1 and V2; (V1pk=30V; V2pk=36V)
   (b) the peak to peak values of voltage for waveforms V1 and V2; (V1pk-pk=60V; V2pk-pk=72V)
   (c) the expected rms values of the two waveforms; (V1=21.2V; V2=25.5V)
   (d) the frequency of the waveforms; (20Hz)
   (e) the phase angle between the two waveforms; (57.6°)
   (f) if V1 leads or lags V2.
   (g) draw a phasor diagram to represent the two voltages, using a scale of 1.0mm = 0.2V.

Figure 1
PHASOR QUANTITIES

PURPOSE:

To develop an understanding of the addition and subtraction of AC quantities by phasor diagram.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Draw the phasor diagram for currents in an AC parallel circuit or voltages in an AC series circuit.
- Determine by phasor addition the total current or voltage in the respective parallel or series AC circuit.
- Measure from the phasor diagram the total current or voltage and circuit phase angle with respect the a chosen reference.
- Determine by phasor subtraction the branch current or component volt drop in a parallel or series AC circuit.
- Measure from the phasor diagram the individual branch current or component volt drop and the phase angle with respect to a chosen reference.

REFERENCES:


Pages 170-172.
1. **ADDITION OF ALTERNATING QUANTITIES**

It has already been shown that in DC circuits the resultant of two voltages is either their numerical sum or difference. For example, consider two batteries as shown in figure 1.

![Figure 1](image1.png)

If these batteries are connected in series so that they assist one another, as shown in the diagram to the left, their resultant voltage is $20 + 30$, or $50V$. On the other hand, if the batteries are connected in series so that they oppose one another, as shown in the diagram to the right, the resultant voltage is only $30 - 20$, or $10V$.

Similarly, *instantaneous values* of two or more alternating voltages and two or more alternating currents may be treated in a similar manner. However, as regards maximum, rms or average values, the numerical addition or subtraction, as the case may be, only applies in two special cases -

(a) where the quantities are in phase with each other

(b) where the quantities are in direct opposition or $180^\circ$ out of phase with each other.

Figure 2 shows two sinusoidal voltage waves which are in phase with each other and having maximum values of $30V$ and $20V$ respectively. The addition of the two waves gives a resultant wave having a maximum value of $50V$.

![Figure 2](image2.png)
If the same two voltages are in opposition, that is, 180° out of phase with each other, as in figure 3, then the maximum value of the resultant voltage would be 10V.

![Figure 3](image1)

If the voltages and currents are neither in phase nor in exact opposition, their resultant maximum, rms and averages values will have some value between their sum and difference.

Figure 4 shows two sinusoidal alternating voltages of maximum values 30V and 20V differing in phase by an angle of 45°.

![Figure 4](image2)

In this diagram instantaneous values of the component voltages are added algebraically to determine the resultant instantaneous voltage, in this case 46.3V at a phase angle of 17.7° lag.

The maximum value of the resultant voltage, however, is not the numerical sum of the respective maximum values, because the component voltages do not attain their maximum values at the same phase angle.

An alternative, and simpler, method for the determination of the resultant voltage would be to use a phasor diagram.
2. PHASOR DIAGRAMS

As described in the previous section, a phasor is a straight line in which its -
(a) length represents the magnitude of the waveform, usually the rms value, and must be drawn to scale
(b) direction represents its phase relationship.

![Voltage phasor](image1) ![Current phasor](image2)

Figure 5

The following rules should be followed when drawing phasors diagrams -
(a) phasors are always drawn with respect to a horizontal reference
(b) a reference is chosen which is a quantity common to all parts of the circuit, for example,
   - current in a series circuit
   - voltage in a parallel circuit
(a) phasors must always be drawn to scale, generally representing the rms value
(b) voltage phasors are always drawn with an open arrowhead
(c) current phasors are always drawn with a closed arrowhead
(d) phasor rotation is always anti-clockwise.

3. PHASOR ADDITION

The addition of AC voltages and currents may be carried out in either of two ways -
(a) numerically adding the voltages and currents, but only if they are in phase
(b) adding the voltages and currents by phasor if they are out of phase.

Phasor addition is achieved by drawing the phasors "tip to tail".
**Example: 1**

For the circuit of figure 6, determine the supply current $I_T$ if:

- $I_1 = 10\,\text{A}$ and lags the supply voltage by $80^\circ$.
- $I_2 = 15\,\text{A}$ and is in phase with the supply voltage.

![Figure 6](image-url)
Example: 2

For the circuit of figure 7, determine the supply voltage if:

- $V_1 = 150\text{V}$ and leads the current by $45^\circ$.
- $V_2 = 80\text{V}$ and lags the current by $90^\circ$.

Figure 7
**Example: 3**

A circuit consists of a heating element in parallel with a single phase motor and is supplied with 240V at 50Hz.

Determine the current drawn from the supply if the -
- motor current is 4A and lags the supply voltage by 30°
- heater current is 3A and is in phase with the supply voltage.

![Circuit Diagram](image-url)
**Example: 4**

The circuit of figure 9 consists of a ballast in series with a resistive heating element. The voltage across the heater is 200V and is in phase with the circuit current. The voltage drop across the inductor is 120V, leading the circuit current by 80°. Determine the value and phase angle of the supply voltage.

![Figure 9](image-url)
4. PHASOR SUBTRACTION

To determine the voltage drop across a component in a series circuit or a branch current in a parallel circuit, phasor subtraction may be used.

Phasor subtraction is achieved by drawing phasors "tip to tip".

**Example: 5**

For the circuit of figure 10, determine the branch current $I_1$ if -
- $I_T = 10A$ and lags the supply voltage by 40º
- $I_2 = 6A$ and lags the supply voltage by 75º.

![Figure 10](image-url)
Example: 6

Determine the voltage drop $V_1$ across the ballast in the series circuit shown in figure 11. The details associated with the circuit are -

- $V = 240V$ and leads the circuit current by $30^\circ$
- $V_2 = 150V$ and is in phase with the current.
Example: 7

For the circuit shown in figure 12, the current lags the supply voltage by 40°. If the voltage drop across the heater is 180V and in phase with the current, determine the voltage drop across the ballast.

![Diagram of the circuit with labeled voltages: V = 240V, V₁, 180V. Ballast and Heater.]
Example: 8

As shown in figure 13, a capacitor is connected in parallel with a single phase motor. The supply current is 4.33A and is in phase with the supply voltage. If the motor current is 5A and lags the supply voltage by 30º, determine the current in the capacitor.

Figure 13
PHASOR ADDITION

PURPOSE:
This practical assignment will be used to examine the application of phasor addition to AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:
At the end of this practical assignment the student will be able to:
- Measure voltages associated with AC circuits.
- Measure currents associated with AC circuits.
- Construct phasor diagrams and use them to apply phasor addition.
- Use phasor diagrams to determine the phase angle between voltages and currents in AC circuits.

EQUIPMENT:

- 1 x variable, single phase AC supply at 50Hz
- 2 x digital multimeters
- 1 x AC current clamp
- 1 x R-L-C panel
- 4mm connection leads

NOTE:
This practical segment is to be completed by students on an individual basis.
The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. PHASOR ADDITION

   1. Connect the circuit shown in figure 1.

   2. Switch on the power supply and adjust to give a supply voltage of 18V, as indicated by the digital multimeter.

   3. Using the digital multimeter, measure the voltage drops across the 390Ω resistor and 40W ballast. Record in table 1.

   4. Using the AC current clamp, measure the circuit current and record in table 1.

   5. Do not proceed until the teacher checks your results and completes the progress table.

| Table 1 |
|------------------|------------------|------------------|
| Supply Voltage | Resistor Voltage Drop | Ballast Voltage Drop | Circuit Current |
| volts          | volts            | volts            | mA              |
| 18V            |                  |                  |                 |

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
6. Switch off the power supply and replace the 40W ballast with a 3.3µF capacitor, as shown in the circuit of figure 2.

![Circuit Diagram](image)

7. Switch on the power supply and adjust to give a supply voltage of 18V, as indicated by the digital multimeter.

8. Using the digital multimeter, measure the voltage drops across the 390Ω resistor and 3.3µF capacitor. Record in table 2.

| Table 2 |
|-----------------|-----------------|-----------------|------------------|
| Supply Voltage volts | Resistor Voltage Drop volts | Capacitor Voltage Drop volts | Circuit Current mA |
| 18V | | | |

9. Using the AC current clamp, measure the circuit current and record in table 2.

10. Do not proceed until the teacher checks your results and completes the progress table.

| Progress Table 2 |
|------------------|------------------|------------------|
| attempt 1 | attempt 2 | attempt 3 |
| 5 | 2 | 0 |
11. Connect the parallel circuit shown in figure 3.

![Figure 3](image)

12. Switch on the power supply and adjust to give a current through the resistor of 40mA, as indicated by the AC current clamp.

13. Using the current clamp, measure the supply current and the current through the capacitor. Record in table 3.

| Table 3 |
|------------------|------------------|------------------|
| Supply Voltage   | Supply Current   | Resistor Current |
| volts            | mA               | mA               |
|                  | 40mA             |                  |

14. Using the digital multimeter measure the supply voltage. Record in table 3.

15. Do not proceed until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

16. Switch off the power supply and replace the 3.3µF capacitor with a 40W ballast, as shown in the circuit of figure 4.

![Figure 4](image)
17. Switch on the power supply and adjust to give a current through the resistor of 50mA, as indicated by the AC current clamp.

18. Using the current clamp, measure the supply current and the current through the capacitor. Record in table 4.

| Table 4 |
|-----------------|-----------------|-----------------|-----------------|
| Supply Voltage  | Supply Current  | Resistor Current | Ballast Current |
| volts           | mA              | mA              | mA              |
|                 |                 | 50mA            |                 |


20. **Do not proceed** until the teacher checks your results and completes the progress table.

| Progress Table 4 |
|------------------|------------------|------------------|
| attempt 1       | attempt 2       | attempt 3       |
| 5               | 2               | 0               |

21. Switch off the supply, then disconnect the circuit.

22. Return all equipment to its proper place, safely and carefully.
2. **OBSERVATIONS:**

1. Using measured values of voltage from table 1, draw the phasor diagram for the circuit of figure 1. Use a scale of 1mm = 0.2V. From the phasor diagram determine -
   - phase angle between the supply voltage and current
   - phase angle between the ballast voltage drop and current.

2. Using measured values of voltage from table 2, draw the phasor diagram for the circuit of figure 2. Use a scale of 1mm = 0.2V. From the phasor diagram determine -
   - phase angle between the supply voltage and current
   - phase angle between the capacitor voltage drop and current.
3. Briefly explain why the numerical sum of the voltage drops in series R-L and R-C circuits does not equal the supply voltage.

4. Using measured values of current from table 3, draw the phasor diagram for the circuit of figure 3. Use a scale of 1mm = 0.5mA. From the phasor diagram determine -
   • phase angle between the supply voltage and current
   • phase angle between the supply voltage and capacitor current.

5. Using measured values of current from table 4, draw the phasor diagram for the circuit of figure 4. Use a scale of 1mm = 1mA. From the phasor diagram determine -
   • phase angle between the supply voltage and current
   • phase angle between the supply voltage and capacitor current.
6. Briefly explain why the numerical sum of the branch current in parallel R-L and R-C circuits does not equal the supply current.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

7. Based on the results of this practical assignment, does phasor addition provide an accurate means of adding voltages in series circuits and currents in parallel AC circuits?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Phasor Quantities

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. Current phasors are represented by an arrow with a/an ______ head, whilst voltage phasors are represented by an arrow with a/an ______ head.
   (a) closed, open
   (b) open, open
   (c) open, closed
   (d) closed, closed

2. The resultant of two or more voltages differing in phase angle may be determined by:
   (a) algebraic addition
   (b) averaging the voltage values
   (c) phasor addition
   (d) numerical addition

3. To find the phasor difference of two phasor quantities, the method to use is:
   (a) tip to tail.
   (b) tip to tip.
   (c) tail to tail.
   (d) non existent.

4. If a phasor is used to show a ______ quantity, it will be drawn above the ______ reference line.
   (a) lagging, horizontal
   (b) leading, horizontal
   (c) leading, vertical
   (d) lagging, vertical

5. The resultant of two voltages, having the same phase angle but different numerical values can be determined by:
Phasor Quantities

(a) numerical addition
(b) numerical subtraction
(c) phasor subtraction
(d) algebraic addition

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. When adding phasor quantities, the method used is described as (a) ___ to (b) ___, but when subtracting phasor quantities, the method used is described as (c) ___ to (d) ___.

7. Phasor addition or subtraction is used to add or subtract quantities which are differing in _____.

8. When solving for series circuits using phasor diagrams, the reference to use is circuit (a) ___, whilst for parallel circuits, the reference to use is circuit (b) ___. These references are used because they are (c) ___ to all parts of their respective circuits.

9. Briefly explain why it is important for phasors to be drawn accurately and to scale.

10. If a phasor quantity leads the reference phasor, it is drawn (a) ___ the reference, and if a phasor quantity lags the reference phasor, it is drawn (b) ___ the reference.

11. List three advantages of using phasor diagrams for phasor addition or subtraction over using waveform diagrams for waveform addition or subtraction.

SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

12. Using a scale of 1mm = 1.0 volts, determine the resultant of the voltages Va and Vb in the diagram of figure 1 by phasor diagram. Clearly label all voltages and angles on your diagram.

13. A heating element is connected in parallel to a 240 volt, 50Hz single phase motor. The current drawn by the heating element is 10A, and is in phase with the supply voltage, whilst the current drawn by the motor is 7A, and lags the supply voltage by 70°. Using a scale of 1mm = 0.1A, determine the current drawn from the supply, and the resultant circuit phase angle.

14. A capacitor is connected in series with a resistor. The voltage across the capacitor is 190 volts leading by 90°, and the voltage across the resistor is 147 volts, and is in phase with the circuit.
current. Using a scale of 1mm = 2.0V, determine the value of voltage connected across the supply, and the resultant circuit phase angle. [240V @ 52° lead]

15. A 240 volt, 50Hz single phase motor draws 18A from the supply at a lagging phase angle of 40°. A capacitor connected across the motor draws 7A at a leading phase angle of 90°. Using a scale of 1mm = 0.2A, determine the current drawn from the supply, and the resultant circuit phase angle. [14.5A @ 18.5° lag]

16. For the circuit of figure 2, determine the value and phase angle for the branch current I2. Use a scale of 1mm = 0.05A. [4.5A @ 90° lead].

Figure 1

Figure 2
RESISTANCE & CAPACITANCE IN AC CIRCUITS

PURPOSE:

To develop an understanding of the effects of resistance and capacitance in an AC circuit.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- state that in a purely resistive AC circuit the voltage and current are in phase and the phase angle is zero degrees.
- calculate the unknown quantity in a resistive AC circuit given two of the following quantities - voltage, current, resistance or power.
- state that in a purely capacitive AC circuit the current leads the voltage by 90° and the phase angle is 90°.
- define the term capacitive reactance.
- calculate the capacitive reactance of a purely capacitive circuit, given capacitance and supply frequency.
- calculate current in a purely capacitive AC circuit given supply voltage, frequency and capacitance.
- describe why the power consumed in a purely capacitive AC circuit is zero.
- describe the effect on capacitive reactance of changing either the capacitance or the supply frequency.
- draw the phasor diagrams for purely resistive and purely capacitive AC circuits.

REFERENCES:

Pages 172-173, 176-177.
1. **FUNDAMENTAL ELEMENTS OF ALTERNATING-CURRENT CIRCUITS**

In alternating current circuits there are three elementary effects of fundamental importance -
- resistance
- inductance
- capacitance.

In many AC circuits, one or more of these elements may be so small in comparison with the others that their effects may be neglected, for example, a lighting circuit may be considered as containing resistance only.

However, most AC circuits contain resistance and inductance in measurable quantities.

It is now intended to discuss the single-phase AC circuits generally encountered in practice.

2. **AC CIRCUITS CONTAINING RESISTANCE ONLY**

In an AC circuit containing resistance only, the current at any instant, in a cycle, can be determined from the expression:

\[ i = \frac{v}{R} \]

where:
- \( i \) = instantaneous value of current
- \( v \) = instantaneous value of voltage
- \( R \) = resistance of circuit.

Thus it is seen that in a circuit of this nature the voltage and current waves are _________ with each other, as shown in figure 1.

![Figure 1](image-url)
Given the voltage and current waves are in phase, the phase angle for a purely resistive circuit must be -

\[
\text{Phase angle} = \text{__________}.
\]

Therefore, the phasor diagram to represent voltage and current in a purely resistive AC circuit would be as shown in figure 2.

Figure 2

Since the equation, \( i = \frac{v}{R} \) can be used to determine instantaneous values of current when a circuit contains resistance only, then similarly the rms value of current in a purely resistive circuit may be determined using -

\[
I = \text{rms value of current} \\
V = \text{rms value of voltage} \\
R = \text{circuit resistance}.
\]

When considering power in an AC circuit, consideration must be given to the magnitude of both voltage and current.

The power wave for any AC circuit can be obtained by multiplying together instantaneous values of voltage and current.
Figure 3 shows the power wave obtained when a voltage of sinusoidal wave form is applied to a circuit containing resistance only.

![Figure 3](image)

It should be noted from figure 3 the power wave is -
- sinusoidal in shape
- is always positive because the voltage and the current are always in the same direction
- has a frequency that is double that of the voltage and current waveforms.

The average or mean height of the power wave is equal to half its peak to peak value, that is $\frac{1}{2} V_{m} \times I_{m}$.

In order to determine power dissipated using rms values, the following is applied -

\[
P = \frac{1}{2} \times \sqrt{2} V \times \sqrt{2} I = \frac{1}{2} \times 2 \times V \times I
\]

where:
- $P =$ average power dissipated in watts
- $V =$ rms value of voltage
- $I =$ rms value of current

That is, the average or mean power, $P$, is expressed as the product of rms values of voltage and current respectively.
It can be also proved that the average power in an ac circuit containing resistance only is expressed as follows -

\[
P = \frac{V^2}{R}
\]

In other words, the determination of the power dissipated by a resistor in an AC circuit is carried out in the same manner as in DC circuits.

**Example: 1**
A sinusoidal alternating emf of 240 volts is applied to a circuit of resistance 60 ohms. Calculate:
(a) rms value of current;
(b) the power absorbed.

**Example: 2**
A purely resistive circuit is supplied from a 24V, 50Hz supply and takes a current of 1.25A. Determine the -
(a) circuit resistance
(b) power dissipated.

**Example: 3**
A purely resistive AC circuit takes a current of 4mA and has a resistance of 2.2\(\Omega\). Determine the -
(a) voltage applied to the circuit
(b) power dissipated by the resistor.
3. PURELY CAPACITIVE AC CIRCUIT

A purely capacitive AC circuit is a circuit in which the only component is a capacitor.

It has already been shown, in Applied Electricity 2, that a current can be maintained in a circuit containing a capacitor provided the voltage applied is of a varying nature.

Consider a sinusoidal wave of voltage applied to the plates of a capacitor as in figure 4.

\[
\begin{align*}
V & \quad C \\
\end{align*}
\]

Figure 4

Since the charge on the plates of the capacitor is proportional to the potential difference between the plates (\(Q = CV\)), then the charge is maximum when the potential difference is maximum and zero when the potential difference is zero.

Consequently the waves of charge, \(Q\), and applied voltage, \(V\), must be in phase with each other, as shown in figure 5.

\[
\begin{align*}
0^\circ & \text{ to } 90^\circ - \text{ the capacitor } \\
90^\circ & \text{ to } 180^\circ - \text{ the capacitor } \\
180^\circ & \text{ to } 270^\circ - \text{ the capacitor } \\
270^\circ & \text{ to } 360^\circ - \text{ the capacitor }
\end{align*}
\]

From figure 5 it can also be seen that the capacitor charges and discharges twice per cycle.
The current in a purely capacitive AC circuit at any instant is equal to the rate of change of charge, as shown in figure 6.

![Figure 6](image)

With reference to figure 6, the following should be observed -

- At 0° - since the charge is increasing at its greatest rate, the current is maximum and positive.
- At 90°, the voltage and hence the charge is unchanging for an instant, thus the current is zero.
- At 180° the current is again maximum, but negative, because the charge is decreasing at its greatest rate.
- At 270° the current is again zero and at D, or 360° maximum and positive.

Based on the preceding observations the following can be stated -

- in the purely capacitive AC circuit the current ________ the voltage by a phase angle of ________.

Therefore, the phasor diagram to represent voltage and current in a purely capacitive AC circuit would be as shown in figure 7.

![Figure 7](image)
4. CAPACITIVE REACTANCE

The opposition to the flow of alternating current through a capacitor is known as the _________________ of the capacitor.

It has been shown that the current in an AC circuit containing resistance only is expressed by the equation:

\[ I = \frac{V}{R} \text{ amperes} \]

It can be proved the current in an AC circuit containing capacitance only is expressed by the equation:

\[ I = \frac{V}{X_C} \]

where: \( X_C = \) capacitive reactance measured in ohms
\( V = \) voltage across the capacitor in volts
\( I = \) current through the capacitor in amperes.

That is, the capacitive reactance of a capacitor is the ratio of the rms value of applied voltage to the rms value of current in a purely capacitive AC circuit.

**Example: 4**

A capacitor takes a current of 4.7A from a 240V, 50Hz supply. Calculate the capacitive reactance of the capacitor.

The capacitive reactance is determined by two factors -

- _________________
- _________________

When these two factors are combined, the capacitive reactance of the capacitor may be calculated -

\[ X_C = \frac{V}{fC} \]

where: \( X_C = \) capacitive reactance in ohms
\( f = \) frequency of the supply in Hertz
\( C = \) capacitance of the capacitor in farads.
Example: 5
A capacitor has a capacitance of 100µF. Compare its capacitive reactance at a frequency of 25 hertz with that at 50 hertz.

It should be noted that capacitive reactance is inversely proportional to the frequency of supply, for example if the frequency is doubled, the capacitive reactance is halved.

Example: 6
A 16µF capacitor is connected to a 240V, 50Hz supply. Calculate the-
(a) capacitive reactance of the capacitor
(b) current taken by the capacitor from the supply.

5. POWER IN A PURELY CAPACITIVE AC CIRCUIT

The power wave for a purely capacitive AC circuit can be obtained by multiplying together instantaneous values of voltage and current for various phase angles.

Figure 8 illustrates the power wave for a purely capacitive AC circuit.
It should be observed from figure 8 that the average power consumed by a purely capacitive AC circuit over one complete cycle is ___________.

This comes about because the power required to charge the capacitor while the voltage is increasing is returned to the supply as the capacitor discharges when the supply voltage decreases.

**Example: 7**

A 10µF capacitor is connected to a 240V, 50Hz supply. Complete the following -
(a) calculate the capacitive reactance of the capacitor
(b) calculate the current taken from the supply by the capacitor
(c) determine the power dissipated by the circuit
(d) draw the phasor diagram for the circuit. Scale: 1mm = 2V and 1mm = 0.01A

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PURELY RESISTIVE & CAPACITIVE CIRCUITS

PURPOSE:

This practical assignment will be used to examine the characteristics of purely resistive and purely capacitive AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect both purely resistive and purely capacitive AC circuits.
- Measure voltages and currents associated with resistive and capacitive AC circuits.
- Construct phasor diagrams from results obtained by measurement.
- Use the CRO to determine the phase angle for purely resistive and purely capacitive AC circuits.
- State the factors that effect the capacitive reactance of a capacitor.

EQUIPMENT:

- 1 x variable, single phase AC supply at 50Hz
- 1 x CRO + 2 leads
- 1 x 0-100µF switched capacitance box
- 4 x 10W wire wound resistors - 1 each 1Ω, 100Ω, 150Ω and 330Ω
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. PURELY RESISTIVE CIRCUIT

1. Connect the circuit shown in figure 1.

![Diagram of the circuit](image)

CRO Settings

Channel 1 = 10V/div
Channel 2 = 0.2V/div
Sweep Time = 5mS/div

Figure 1

2. Switch on the power supply and adjust to give a supply voltage of 30V, as indicated by the digital multimeter.

3. Using the AC current clamp and digital multimeter, measure the current flowing in the circuit. Record in table 1.

<table>
<thead>
<tr>
<th>Nominal Resistance (ohms)</th>
<th>Supply Voltage (volts)</th>
<th>Circuit Current (mA)</th>
<th>Circuit Phase Angle (degrees)</th>
<th>Actual Resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>330Ω</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150Ω</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100Ω</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Using the CRO, measure the phase angle between the supply voltage and current.

5. Replace the 330Ω resistor with a 150Ω resistor and repeat the procedure.

6. Replace the 150Ω resistor with a 100Ω resistor and repeat the procedure.

7. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
2. PURELY CAPACITIVE CIRCUIT

1. Connect the circuit shown in figure 1.

![Circuit Diagram](image)

<table>
<thead>
<tr>
<th>CRO Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel 1 = 10V/div</td>
</tr>
<tr>
<td>Channel 2 = 0.2V/div</td>
</tr>
<tr>
<td>Sweep Time = 5mS/div</td>
</tr>
</tbody>
</table>

Figure 2

2. Switch on the power supply and adjust to give a supply voltage of 30V, as indicated by the digital multimeter.

3. Using the AC current clamp and digital multimeter, measure the current flowing in the circuit. Record in table 2.

<p>| Table 2 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Nominal Capacitance µF</th>
<th>Supply Voltage volts</th>
<th>Circuit Current mA</th>
<th>Circuit Phase Angle degrees</th>
<th>Capacitive Reactance ohms</th>
<th>Actual Capacitance µF</th>
</tr>
</thead>
<tbody>
<tr>
<td>10µF</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20µF</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30µF</td>
<td>30V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Using the CRO, measure the phase angle between the supply voltage and current.

5. Switch in an additional 10µF to give 20µF's total and repeat the procedure.

6. Switch in an additional 10µF to give 30µF's total and repeat the procedure.

7. **Do not proceed** until the teacher checks your results and completes the progress table.

| Progress Table 2 |
|------------------|------------------|------------------|
| attempt 1 | attempt 2 | attempt 3 |
| 5 | 2 | 0 |
3. **VARIATION OF CAPACITIVE REACTANCE WITH FREQUENCY**

1. Connect the parallel circuit shown in figure 3.

   ![Diagram of parallel circuit](image)

   Figure 3

2. Switch on the signal generator and adjust to give a supply voltage of 0.5V at a frequency of 30Hz.

3. Using the AVO8, measure the supply current. Record in table 3.

<table>
<thead>
<tr>
<th>Supply Frequency (hertz)</th>
<th>Supply Voltage (volts)</th>
<th>Supply Current (mA)</th>
<th>Capacitive Reactance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Adjust the signal generator to give a supply voltage of 0.5V at a frequency of 40Hz.

5. Using the AVO8, measure the supply current. Record in table 3.

6. Repeat the procedure for supply frequencies of 50, 60 and 70Hz.

7. **Do not proceed** until the teacher checks your results and completes the progress table.

   Progress Table 3
   
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

8. Switch off the supply, then disconnect the circuit.

9. Return all equipment to its proper place, safely and carefully.
4. **OBSERVATIONS:**

1. Apply Ohm's law to the circuit of figure 1, to determine the actual resistance of each resistor used. Record your answers in the appropriate column of table 1.
   \[ R = \frac{V}{I} \text{ ohms} \]

2. Based on your results, can Ohm's law be applied to a purely resistive AC circuit?

3. What is the phase relationship between voltage and current in a purely resistive AC circuit?

4. Calculate the power dissipated in each of the three resistors used in the circuit of figure 1.

5. Using measured values of voltage and current for the circuit of figure 2, determine the capacitive reactance for the three values of capacitance. Record your answers in the appropriate column of table 2.
   \[ X_C = \frac{V}{I} \text{ ohms} \]
6. Calculate the actual value of capacitance for the three values of capacitance used in the circuit of figure 2. Use the values of $X_C$ determined in question 5.

$$C = \frac{1}{2\pi f X_C} \text{ ohms}$$

7. What is the phase relationship between voltage and current in a purely capacitive AC circuit?

8. Using measured values of voltage and current for the circuit of figure 3, determine the capacitive reactance of the capacitor at each supply frequency. Record your answers in the appropriate column of table 3.

$$X_C = \frac{V}{I} \text{ ohms}$$

9. Based on the results recorded in table 2, what is the relationship between capacitive reactance and capacitance?
10. Using the values recorded in table 3, plot the graph of capacitive reactance versus frequency for the capacitor.

![Graph of capacitive reactance versus frequency](image)

11. What is the relationship between the capacitive reactance of a capacitor and the supply frequency?

12. Draw the phasor diagram for the purely resistive circuit of figure 1, with the 330Ω resistor connected.

13. Draw the phasor diagram for the purely capacitive circuit of figure 2, with the 10µF capacitor connected.
Resistance & Capacitance in AC Circuits

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The phase angle ($\phi$) between voltage and current in a purely resistive circuit is:
   (a) 180 electrical degrees.
   (b) 90 electrical degrees.
   (c) 45 electrical degrees.
   (d) 0 electrical degrees.

2. The opposition to current flow in a purely capacitive circuit is known as ______ and is measured in ______
   (a) capacitive reactance, ohms
   (b) resistance, ohms
   (c) capacitive reactance, farads
   (d) impedance, farads

3. The phase angle ($\phi$) between voltage and current in a purely capacitive circuit is:
   (a) 180 electrical degrees.
   (b) 90 electrical degrees.
   (c) 45 electrical degrees.
   (d) 0 electrical degrees.

4. Adding extra resistance to a purely resistive circuit will cause the phase angle ($\phi$) between voltage and current to:
   (a) increase.
   (b) decrease.
   (c) remain unchanged.
   (d) become maximum.
5. The capacitive reactance of a capacitor is inversely proportional to the ______ and ______ value.
   (a) supply frequency, capacitance
   (b) supply current, capacitance
   (c) supply frequency, supply voltage
   (d) supply voltage, capacitance

6. Adding extra capacitance to a purely capacitive circuit will cause the phase angle \((\phi)\) between voltage and current to:
   (a) increase.
   (b) decrease.
   (c) remain unchanged.
   (d) become maximum.

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

7. The power dissipation in an AC circuit is known as the ___(a)___ power, and for a capacitive circuit is equal to ___(b)___.

8. In a purely resistive circuit, the circuit current and the circuit voltage are ______.

9. If extra resistance is added to a purely resistive circuit, the equivalent circuit resistance can be found by ______.

10. In a purely capacitive circuit, the circuit current and the circuit voltage are ___(b)___, and the current ___(b)___ the voltage by ___(c)___.

11. The capacitive ___(a)___ of a capacitor is measured in ohms because it ___(b)___ current flow.

12. A capacitor "looks" like an ___(a)___ circuit to a DC supply once it is charged, but "looks" like a ___(b)___ circuit to an AC supply due to the charge and discharge ___(c)___ that are continuously flowing.

13. A purely resistive AC circuit can be treated in the same manner as a ___(a)___ circuit. This is because the phase angle \((\phi)\) in a resistive circuit is ___(b)___.
SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

14. A circuit of 20Ω resistance draws 16A when connected to an AC supply. Determine:
   (a) the voltage applied to the circuit, (320V)
   (b) the power consumed by the circuit, (512kW)

15. A heating element is connected to a 240 volt, 50Hz supply. If the rating of the heater is 1.5kW, determine the current flowing in the circuit. (6.25A)

16. Determine the capacitive reactance of a 47μF capacitor when connected to a 32V, 50Hz supply. (67.7Ω]

17. Determine the current taken by a 390μF capacitor when connected to a 240V, 50Hz supply. (29.4A)

18. A capacitor takes 3A when connected to a 240V, 50Hz supply. Determine:
   (a) the capacitive reactance of the capacitor; (80Ω)
   (b) the capacitance of the capacitor. (39.8μF)

19. A capacitor takes 6A when connected to a 240V, 50Hz supply. Determine how much current the capacitor will take if it is reconnected to a 115V, 400Hz supply. (23A)

20. For the circuit of figure 1, determine:
   (a) the resistances of R1 and R2; (4.8Ω; 3.43Ω)
   (b) the current taken from the supply; (12A)
   (c) the equivalent resistance of the circuit; (2Ω)
   (d) the power dissipated by each resistive (120W; 168W)
   (e) the total power dissipated by the circuit, (288W)
   (f) draw the phasor diagram for the circuit.

21. For the circuit of figure 2, determine:
   (a) the capacitive reactances of C1 and C2; (56.8Ω; 81.6Ω)
   (b) the capacitances of C1 and C2; (56μF; 39μF)
   (c) the current taken from the supply; (7.16A)
   (d) the equivalent capacitive reactance of the circuit; (33.5Ω)
   (e) the equivalent capacitance of the circuit (95μF);
   (f) the total power dissipated by the circuit, (0W)
   (g) draw the phasor diagram for the circuit.
***NOTES***
PURELY INDUCTIVE AC CIRCUITS

PURPOSE:

To develop an understanding of the effects of inductance in an AC circuit.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

• state that in a purely inductive AC circuit the voltage and current are 90° out of phase with the current lagging the voltage.
• define the term inductive reactance.
• calculate the inductive reactance of a purely inductive circuit, given inductance and supply frequency.
• calculate current in a purely inductive AC circuit given supply voltage, frequency and inductance.
• describe why the power consumed in a purely inductive AC circuit is zero.
• describe the effect on inductive reactance of changing either the inductance or the supply frequency.
• draw the phasor diagram for a purely inductive AC circuit.

REFERENCES:

1. **INDUCTANCE**

As shown in Applied Electricity 3, if a coil is connected to a battery as in figure 1, then the energising current produces a magnetic flux which links the coil.

![Figure 1](image)

As the flux builds up whilst the current is being established an emf is induced in the coil the magnitude of which depends on the -

- number of turns in the coil
- the rate at which the flux increases.

The emf so induced is called an emf of ________________________________.

According to Lenz’s law -

- the direction of the emf of self induction must always be such that it tends to produce a current which would ______________ the increase of flux.

When the switch is opened -

- the current falls to ___________
- consequently the flux produced by the current also falls to ________.
- during the time, in which the flux is falling, an emf is induced due to the cutting action of the flux falling through the coil conductors.
  
  Again, this emf is known as an emf of ____________________________.
- by Lenz’s law the direction of the emf of self induction must be such that it tends ______________ the falling current and subsequent decrease of flux.

The emf of self induction will always have a polarity such that it ______________ an increase or decrease in current. For this reason, the emf of self induction is often known as the -

______________________________.

The property of a conductor or coil to produce an emf of self induction and its subsequent opposition to a change in current is known as the -

_______________________ or ________________________________ of the coil.
Figure 2 shows the growth of current when a DC voltage is applied to an inductive circuit and the decay of current when the supply is disconnected and the circuit short-circuited.

It may be said that the inductance of a circuit provides the current with the property of inertia, that is, the tendency to resist any change in magnitude.

2. UNIT OF INDUCTANCE

The unit of inductance is the henry (H) and is defined as follows.

A circuit has an inductance of one henry when a current of one ampere produces a flux-linkage of one weber-turn.

Alternatively -

A circuit in which the current changes at the rate of one ampere per second and produces an emf of 1 volt is said to have an inductance one henry.

The inductance of a coil is calculated using the equation:

\[ L = \frac{N \mu A}{l} \]

where:  
N = number of coil turns  
\( \mu \) = permeability of the flux path  
A = cross sectional area within the coil  
l = length of the flux path.
3. **PURELY INDUCTIVE AC CIRCUIT**

A purely inductive circuit is a circuit in which the effects of resistance and capacitance are negligible.

Consider a purely inductive circuit carrying an alternating current of sinusoidal wave form, as shown in figure 3.

![Figure 3](image)

The changing current in this circuit sets up a varying magnetic field which produces a counter emf of self-induction in the circuit.

Figure 4 shows the applied voltage, self-induced emf and current waves for the circuit.

![Figure 4](image)
From figure 4 it will be observed that the self-induced emf:

- is maximum and negative in sign at 0°. Because the induced emf is proportional to the rate of change of current and since the wave form is sinusoidal the current is changing at its greatest rate when passing through zero.
- is negative in sign at 0°. Because the current is increasing in a positive direction and from Lenz’s law the induced emf must try to prevent the current from increasing, that is, it must act in the opposite or negative direction.
- decreases as the phase angle increases between 0 and 90°. Due to a decrease in the rate of change of current.
- is zero at 90°. The current is at its maximum value and is therefore unchanging for an instant, hence the self-induced emf is zero.
- between 90° and 180°, the current is decreasing at the same rate as it increased between 0° and 90°, thus the self-induced emf must now act in a positive direction to try to prevent the reduction of current.
- at 180° the current is decreasing at its maximum rate, hence the self-induced emf is maximum.
- between 180° and 270°, the current is increasing in the negative direction, and the self-induced emf must act in the positive direction.
- at 270°, the current is again maximum and unchanging for an instant, therefore the self-induced emf is again zero.
- between 270° and 360°, the current is decreasing in the negative direction, hence the self-induced emf must act in the same direction to try to prevent the reduction of current.
- at 360°, the self-induced emf is again maximum as the current is once more changing at its greatest rate.

Thus it is seen that the wave of self-induced voltage is also sinusoidal in shape.

Since the circuit under consideration is assumed to be purely inductive the applied voltage is only required to overcome the self-induced emf, hence it must be equal and opposite to it at every instant in the cycle as shown in figure 4.

It will be seen from figure 4 that in a purely inductive AC circuit the current _____________ behind the applied voltage by an angle of ________.

Figure 5 shows the phasor diagram for a purely inductive AC circuit. In this diagram the phasors V and I represent the rms values of applied voltage and current respectively.
4. INDUCTIVE REACTANCE

The opposition to the flow of alternating current through an inductor is known as
__________________________ ___________________.

Inductive reactance is defined as the ratio of the emf of self-induction in an AC circuit to the
current.

where: \( V \) = supply voltage in volts
\( I \) = circuit current in amperes

The practical unit of inductive reactance is the ohm.

Example: 1
The voltage applied to an ideal inductor was 240V at 50Hz. If the circuit current was
measured to be 1.8A, determine the inductive reactance of the inductor.

5. FACTORS AFFECTING INDUCTIVE REACTANCE

The value of the self-induced emf in an inductor is dependent on -

- the inductance of the inductor
- rate of change of current in amperes per second.

\[ V = L \times \text{rate of change of current} \]

As inductive reactance \( X_L = \frac{V}{I} \)

\[ X_L = \frac{L \times \text{rate of change of current}}{I} \]

It can be proved for sinusoidal waveform -

the rate of change of current = \( 2\pi f \) amperes per second

\[ \therefore \quad X_L = \frac{L \times 2\pi f}{I} \]
Therefore, the inductive reactance of an inductor may be calculated provided the supply frequency and inductance are known -

where: \( \pi = 3.142 \)
\( f = \) frequency in hertz
\( L = \) inductance in henries

**Example: 2**
A coil has an inductance of 0.02 henry. Determine its inductive reactance for the following frequencies:
(a) 25 hertz
(b) 50 hertz
(c) 100 hertz.

It should be noted from example 2 that the inductive reactance of a coil is directly proportional to the -

• __________________________
• __________________________

**Example: 3**
A contactor coil of negligible resistance draws a current of 0.2A from a 240V, 50Hz supply. Determine the inductance of the coil.
**Example: 4**
A coil of negligible resistance and inductance of 0.15 henry is connected to a 240V, 50Hz supply. Calculate the coil current.

---

**Example: 5**
If the coil of example 4 is connected to a 240V, 25Hz supply, determine the current.

---

6. **POWER IN A PURELY INDUCTIVE AC CIRCUIT**

Figure 6 shows the waves of applied voltage, current and power for a purely inductive AC circuit.

![Diagram showing voltage, current, and power waves](image)

**Figure 6**

The power wave is obtained by multiplying the instantaneous values of voltage and current for a number of phase angles over a complete cycle and then plotting the results of these products.
With reference to the waveforms shown in figure 6 -

- between 0° and 90°, the instantaneous values of voltage (e) and current (i) are both positive, therefore the product e x i, that is, the instantaneous power is positive for any phase angle. The power supplied from the mains between 0° and 90° is indicated by the area enclosed by the power wave and is used in building-up the magnetic field while the current is increasing.

- between 90° and 180°, the values of e are negative (-) and i are positive (+), therefore the product -e x i is negative. This means that power is being returned to the mains due to the collapse of the field as the current decreases.

- between 180° and 270°, the values of e and i are both negative but the product -e x -i is positive, that is, power is again being used in building up the field while the current is increasing in the negative direction.

- between 270° and 360° the product e x -i is again negative and power is again returned to the mains as the field collapses.

The power curve is distributed equally above and below the base line, therefore the average power in a purely inductive AC circuit is ____________.

Therefore one of the great advantages of the inductor is its ability to provide opposition to current flow, yet not consume power. Unlike the resistor, that also provides opposition to current flow, but always dissipates some level of power.

A prime application of the current limiting ability of the inductor is the ballast, as used in fluorescent light fittings. Its purpose is to limit current flow through the fluorescent lamp, but dissipate minimum power.
INDUCTIVE AC CIRCUITS

PURPOSE:

This practical assignment will be used to examine the characteristics of inductive AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect an inductive AC circuits.
- Measure voltages and currents associated with an inductive AC circuit.
- Construct phasor diagrams from results obtained by measurement.
- Use the CRO to determine the phase angle for an inductive AC circuit.
- State the effect that increased supply frequency has on the inductive reactance of an inductor.

EQUIPMENT:

☐ 1 x variable, single phase AC supply at 50Hz
☐ 1 x CRO + 2 leads
☐ 1 x 40W ballast (RLC panel)
☐ 1 x AVO8 multimeter
☐ 2 x digital multimeters
☐ 1 x AC current clamp
☐ 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.

The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -

observe correct isolation procedures
PROCEDURE:

1. **INDUCTIVE CIRCUIT**

   1. Using the digital multimeter on the ohms range measure the resistance of the ballast.
      
      Ballast resistance = __________ ohms

   2. Connect the circuit shown in figure 1.

   ![Circuit Diagram](image)

   CRO Settings
   
   - Channel 1 = 10V/div
   - Channel 2 = 0.2V/div
   - Sweep Time = 5mS/div

   Figure 1

3. Switch on the power supply and adjust to give a supply voltage of 30V, as indicated by the digital multimeter.

4. Using the AC current clamp and digital multimeter, measure the current flowing in the circuit. Record in table 1.

   ![Table](image)

   Table 1

<table>
<thead>
<tr>
<th>Supply Voltage volts</th>
<th>Circuit Current mA</th>
<th>Circuit Phase Angle degrees</th>
<th>Apparent Resistance ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>30V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Using the CRO, measure the phase angle between the supply voltage and current. To do so accurately change the sweep time setting to 2mS/div.

   Period of the wave $T = \_\_\_\_\_\_\_\_\_$

   Time displacement $TD = \_\_\_\_\_\_\_\_$

   Phase angle $= \frac{T D}{T} \times 360 = \_\_\_\_\_\_$ x 360$° $= \_\_\_\_\_\_$

6. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 1**

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
2. **VARIATION OF INDUCTIVE REACTANCE WITH FREQUENCY**

1. Connect the circuit shown in figure 2.

![Diagram](image)

Figure 3

2. Switch on the signal generator and adjust to give a supply voltage of 1.0V at a frequency of 30Hz.

3. Using the AVO8, measure the supply current. Record in table 2.

<table>
<thead>
<tr>
<th>Supply Frequency hertz</th>
<th>Supply Voltage volts</th>
<th>Supply Current mA</th>
<th>Approximate Inductive Reactance ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Adjust the signal generator to give a supply voltage of 1.0V at a frequency of 40Hz.

5. Using the AVO8, measure the supply current. Record in table 3.

6. Repeat the procedure for supply frequencies of 50, 60 and 70Hz.

7. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

8. Switch off the supply, then disconnect the circuit.

9. Return all equipment to its proper place, safely and carefully.
3. **OBSERVATIONS:**

1. Apply Ohm’s law to the circuit of figure 1, to determine the apparent resistance of the ballast used. Record your answer in the appropriate column of table 1.
   \[ R = \frac{V}{I} \text{ ohms} \]

2. Compare the measured ballast resistance with the apparent resistance from the test results. Why the difference in values?

3. What is the phase relationship between voltage and current in an inductive AC circuit?

4. Using measured values of voltage and current for the circuit of figure 2, determine the approximate inductive reactance of the ballast at each supply frequency. Record your answers in the appropriate column of table 2.
   \[ X_L = \frac{V}{I} \text{ ohms} \]
5. Using the values recorded in table 2, plot the graph of approximate inductive reactance versus frequency for the ballast.

6. What is the relationship between the capacitive reactance of a capacitor and the supply frequency?

7. Draw the phasor diagram for the inductive circuit of figure 1.
Inductance in AC Circuits

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The phase angle $\phi$ between voltage and current in a purely inductive circuit is:
   (a) 0 electrical degrees.
   (b) 45 electrical degrees.
   (c) 90 electrical degrees.
   (d) 180 electrical degrees.

2. The opposition to current flow in a purely inductive circuit is known as ______ and is measured in ______
   (a) resistance, ohms
   (b) inductive reactance, ohms
   (c) inductive reactance, henries
   (d) impedance, henries

3. Adding extra inductance to a purely inductive circuit will cause the phase angle $\phi$ between voltage and current to:
   (a) increase.
   (b) decrease.
   (c) remain unchanged.
   (d) become maximum.

4. Inductors (such as ballasts) are used to control current in AC circuits as they:
   (a) have a low power loss.
   (b) have a good power factor.
   (c) are cheaper than resistors.
   (d) have a low value of reactance.
5. The inductive reactance of a inductor is ______ to the supply frequency and ______ to the circuit inductance value.
   (a) proportional, inversely proportional
   (b) proportional, proportional
   (c) inversely proportional, inversely proportional
   (d) inversely proportional, proportional

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. The power dissipation for an inductive circuit is equal to ___(a)____. This is because the energy is returned to the supply when the ___(b)____ collapses.

7. Inductive reactance is an example of ______ Law "in action".

8. In a purely inductive circuit, the circuit current and the circuit voltage are ___(b)____, and the current ___(b)____ the voltage by ___(c)____. This is due to the ___(d)____ that is continuously generated in the inductor.

9. The inductive ___(a)____ of an inductor is measured in ___(b)____ because it opposes current flow.

10. An "ideal" inductor has ___(a)____ resistance, whilst a practical inductor has ___(b)____.

11. As the frequency of a supply connected to an ideal coil increases, the ___(a)____ ___(b)____ of the coil increases.

**SECTION B**

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

12. When connected to a 24V, 50Hz supply, an ideal inductor draws 1.2A. Determine the reactance of the inductor. (20Ω)

13. If a coil of negligible resistance has an inductance of 0.05 henry, determine its inductive reactance if connected to a:
   (a) 50Hz supply, (15.7Ω)
   (b) 33Hz supply, and (10.4Ω)
   (c) 1kHz supply. (314Ω)

14. A coil of negligible resistance draws 0.5A when connected to a 240V, 50Hz supply. Determine the inductance of the coil. (1.53H)
15. An ideal 153mH inductor is rated to be used on a 240V, 50Hz supply, but instead is connected to a 200V, 400Hz supply. Determine the current flowing in the inductor for both of these conditions. (@50Hz: 5A; @400Hz: 0.52A)

16. A coil of negligible resistance draws 1A when connected to a 32V, 120Hz supply.
   (a) Determine how much current it will draw from a 415V, 50hz supply. (31.1A)
   (b) Draw a phasor diagram for each of the operating conditions. Pick a suitable scale for each diagram, noting the scales you have used next to your phasor diagrams.
R-L AND R-C SERIES CIRCUITS

PURPOSE:

To develop an understanding of the characteristics of R-L and R-C series AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

• define the term impedance.
• draw phasor diagrams for R-L and R-C series circuits.
• draw impedance triangles for R-L and R-C series circuits.
• determine voltages, currents and impedance associated with R-L and R-C series circuits.
• determine the phase angle for series R-L and R-C circuits, by calculation or phasor diagram.

REFERENCES:

Pages 178-179.
1. **APPLIED VOLTAGE WAVE IN AN R-L SERIES AC CIRCUIT**

Consider a current of I amperes in an AC circuit containing resistance and inductance in series as in figure 1.

![Figure 1](image1)

The instantaneous value of the applied voltage required for any phase angle in the cycle will be the algebraic sum of the instantaneous values of the voltage drops across the resistance and inductive reactance, respectively.

The waves of voltage drop due to resistance, voltage drop due to inductive reactance and applied voltage are shown in figure 2.

![Figure 2](image2)

It should be noted again that -

- the voltage drop due to resistance \( V_R \) is _________ with the current wave \( I \)
- the current _________ the voltage drop due to inductive reactance \( V_L \) by _________.

It can be seen from figure 2, that the current wave \( I \) lags behind the applied voltage wave \( V \) by an angle \( \phi \) which is less than 90°.

Also, the maximum value of the applied voltage wave is less than the numerical sum of the separate maximum voltage drops due to the resistance and reactance, because the maximum values of these two voltages are out of phase.
2. PHASOR DIAGRAM FOR AN R-L SERIES CIRCUIT

The phasor diagram for the circuit of figure 1 is shown in figure 3.

In the phasor diagram of figure 3:
- $V_R = \text{voltage drop across the resistance (in phase with the current)}$
- $V_L = \text{voltage drop across the inductive reactance (90º ahead of the current)}$
- $V = \text{applied voltage and is the phasor sum of } V_R \text{ and } V_L.$

The angle $\phi$ between $V$ and $I$ is the angle by which the current lags behind the applied voltage. This angle of phase difference $\phi$ has the same magnitude as the angle $\phi$ shown in the waves of figure 2.

The voltage triangle shown in figure 4 is obtained from the phasor diagram of figure 3.

By applying the Pythagorean Theorem to the geometry of this triangle, the supply voltage may be determined -

where: $V = \text{the supply voltage}$
$V_R = \text{the voltage drop across the resistance}$
$V_L = \text{the voltage drop across the inductive reactance}.$
Example: 1.

Determine graphically, when the supply frequency is 50 hertz, the voltage which must be applied to the circuit of figure 5 for a current of 10 amperes. Also, verify the result by calculation. Use a scale of 1mm = 0.5V.
3. IMPEDANCE EQUATION FOR AN R-L SERIES AC CIRCUIT

Again consider a current of $I$ amperes in an AC circuit containing resistance and inductance in series as in figure 6.

\[
\begin{align*}
V_{AC} & \quad I \\
R & \quad V_R \\
X_L & \quad V_L \\
\end{align*}
\]

Figure 6

It already been shown that the voltage triangle, figure 7, can be derived from the phasor diagram for this circuit. Dividing each side of the voltage triangle by the current ($I$), gives the arrangement shown in figure 8.

\[
\begin{align*}
V & \quad V_L \\
\phi & \quad \phi \\
V_R & \\
\end{align*}
\]

Figure 7

Figure 8

It is thus seen that the ratio $\frac{V}{I}$, that is, the ratio of applied voltage to current in an AC circuit containing resistance and inductance in series is $\sqrt{R^2 + X_L^2}$.

This ratio $\frac{V}{I}$ is known as the ___________________________ of the circuit.

The symbol for impedance is $Z$.

The unit of measurement for impedance is the ohm.
Thus, to determine the impedance of an R-L series circuit -

Impedance may therefore be defined as the ratio of the rms value of the applied voltage in a circuit to the rms value of current which is produced.

The term impedance was derived from the word impede meaning to obstruct or hinder, hence the impedance of an AC circuit is that property which tends to obstruct or hinder the flow of electricity just as resistance opposes the flow in the case of DC circuits.

Figure 9 shows Fleming's impedance triangle for an AC circuit containing resistance and inductance in series. The quantities represented by the sides of the triangle are resistance (R), inductive reactance ($X_L$), and impedance (Z).

![Figure 9](image)

Provided the circuit resistance and inductive reactance are known, the circuit impedance can be determined -

where: $Z = \text{impedance in ohms}$
$R = \text{resistance in ohms}$
$X_L = \text{inductive reactance in ohms}$.

By the application of basic trigonometry to the triangle shown in figure 9 the phase angle of the circuit may be determined -
Hence, the angle of phase difference between the applied voltage and current in a circuit containing resistance and inductive reactance in series is independent of the voltage or current value and is determined solely by the ratio of inductive reactance to resistance.

Therefore -

- an increase of reactance for a definite value of resistance produces a greater angle of lag of the current behind the applied voltage
- an increase of resistance for a definite value of reactance produces a smaller angle of lag.

**Example: 2**
A circuit has a resistance of 9 ohms in series with an inductive reactance of 12 ohms. If the circuit is connected to a 240V, 50Hz supply, determine the -

(a) impedance of the circuit
(b) circuit current
(c) angle of phase difference between applied voltage and current.

**Example: 3**
A current of 12 amperes is produced when a pd of 240 volts, at a frequency of 50 hertz, is applied to a circuit having a resistance of 16 ohms in series with an inductive reactance. Calculate the -

(a) impedance;
(b) inductive reactance;
(c) inductance.
**Example: 4**

A circuit consists of a resistor having a resistance of 10 ohms in series with an inductance of 25mH. If a 240-volt, 50-hertz supply is applied to the circuit, determine:

(a) current  
(b) voltage drop across resistor  
(c) voltage drop across inductive reactance  
(d) angle of phase difference.
4. PHASOR DIAGRAM FOR AN R-C SERIES AC CIRCUIT

Consider a circuit containing resistance and capacitance in series as shown in figure 10.

![Figure 10](image)

In this circuit the -

- voltage drop \((V_R)\) across the resistor is ______________ with the current
- current ____________ the voltage drop across the capacitor \((V_C)\) by __________.

The applied voltage \(V\) is the resultant of these two component voltages as shown in the phasor diagram of figure 11.

![Figure 11](image)

It should be noted from figure 11 that the current \((I)\) in the circuit leads the applied voltage \((V)\) by an angle \(\phi\), which is less than 90º.
5. **IMPEDANCE EQUATION FOR AN R-C SERIES CIRCUIT**

The voltage triangle shown in figure 12 is obtained from the phasor diagram of figure 11. Dividing each side of the triangle by the current (I), gives the arrangement shown in figure 13.

![Figure 12](image1.png)  
![Figure 13](image2.png)

From the voltage triangles of figures 12 and 13 it can be seen that the ratio of the rms value of applied voltage to the rms current in an AC circuit containing resistance and capacitance in series is equal to $\frac{V}{I} = \sqrt{R^2 + \frac{1}{X_C^2}}$.

The ratio of the applied voltage to current $\frac{V}{I}$, is the impedance of the circuit.

The symbol for impedance is $Z$ and the unit of measurement for impedance is the ohm.

Therefore, the impedance of a series R-C circuit can be calculated using -

$$Z = \sqrt{R^2 + \frac{1}{X_C^2}}$$

where:  
$Z =$ circuit impedance in ohms  
$V =$ supply voltage in volts  
$I =$ circuit current in amperes
Fleming's impedance triangle for a circuit containing resistance and capacitance in series is shown in figure 14.

\[ \Phi \]

Figure 14

From this impedance triangle it should be seen that the impedance can be determined provided the values of resistance and capacitive reactance are known. Applying the Pythagorean theorem -

\[ Z = \sqrt{R^2 + X_C^2} \]

where:  
\( Z \) = circuit impedance in ohms  
\( R \) = circuit resistance in ohms  
\( X_C \) = capacitive reactance in ohms

By the application of basic trigonometry to the impedance triangle shown in figure 14 the phase angle of the circuit may be determined -

\[ \tan(\phi) = \frac{X_C}{R} \]
Example: 5
A 120Ω resistor and a 60μF capacitor are connected in series across a 300V, 50Hz supply. Determine the -
(a) circuit impedance
(b) circuit current
(c) angle of phase difference
(d) voltage drop across resistor and voltage drop across capacitor.

Example: 6
For the circuit shown in figure 15, determine -
(a) circuit impedance
(b) circuit current
(c) circuit phase angle
(d) voltage drops across the resistor and capacitor.

Figure 15
**R-L & R-C SERIES AC CIRCUITS**

**PURPOSE:**

This practical assignment will be used to examine the characteristics of R-L and R-C series AC circuits.

**TO ACHIEVE THE PURPOSE OF THIS SECTION:**

At the end of this practical assignment the student will be able to:

- Connect both R-L and R-C series AC circuits.
- Measure voltages and currents associated with R-L and R-C series AC circuits.
- Construct phasor diagrams from results obtained by measurement.
- Use the CRO to determine the phase angle for R-L and R-C series AC circuits.
- Verify the voltage applied to a series AC circuit is equal to the phasor sum of the circuit voltage drops.

**EQUIPMENT:**

- 1 x variable, single phase AC supply at 50Hz
- 1 x CRO + 2 leads
- 1 x R-L-C panel
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

**NOTE:**

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

**- REMEMBER -**

- WORK SAFELY AT ALL TIMES -

observe correct isolation procedures
PROCEDURE:

1. **R-L SERIES AC CIRCUIT**

   1. Connect the circuit shown in figure 1.

   ![Circuit Diagram](image)

   **CRO Settings**
   - Channel 1 = 10V/div
   - Channel 2 = 10V/div
   - Sweep Time = 5mS/div

   2. Be sure to adjust the two CRO traces to exactly the vertical centre of the screen.

   3. Switch on the power supply and adjust to give a circuit current of 40mA, as indicated by the AC current clamp.

   4. Using the digital multimeter, measure the supply voltage, ballast voltage drop and the resistor voltage drop. Record in table 1.

   **Table 1**

<table>
<thead>
<tr>
<th>Circuit Current mA</th>
<th>Supply Voltage volts</th>
<th>Ballast Voltage Drop volts</th>
<th>Resistor Voltage Drop volts</th>
<th>Circuit Phase Angle degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>40mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   5. Using the CRO measure the periodic time of the supply voltage.

   \[
   \text{Periodic Time} = \underline{\text{________}}
   \]

   6. Adjust the sweep time/div. to 2mS/div.

   7. Using the CRO, measure the time displacement between the supply voltage and current.

   \[
   \text{Time Displacement} = \underline{\text{________}}
   \]
8. Determine the circuit phase angle and record in table 1.

\[
\text{Phase Angle} = \frac{\text{Time Displacement}}{\text{Periodic Time}} \times 360 = \text{__________}
\]

9. From the waveforms displayed on the CRO complete the following statement -

The circuit current (leads/lags) ______________ the supply voltage.

10. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

2. **R-C SERIES AC CIRCUIT**

1. Connect the circuit shown in figure 2. Note, the overall capacitance of 5.5\(\mu\)F is made up of a 2.2\(\mu\)F capacitor in parallel with a 3.3\(\mu\)F capacitor.

2. Be sure to adjust the two CRO traces to exactly the vertical centre of the screen.

3. Switch on the power supply and adjust to give a circuit current of 40mA, as indicated by the AC current clamp.

4. Using the digital multimeter, measure the supply voltage, capacitor voltage drop and the resistor voltage drop. Record in table 2.
Table 3

<table>
<thead>
<tr>
<th>Circuit Current mA</th>
<th>Supply Voltage volts</th>
<th>Capacitor Voltage Drop volts</th>
<th>Resistor Voltage Drop volts</th>
<th>Circuit Phase Angle degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>40mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Using the CRO measure the periodic time of the supply voltage.
   
   Periodic Time = ________________

6. Adjust the sweep time/div. to 2mS/div.

7. Using the CRO, measure the time displacement between the supply voltage and current.
   
   Time Displacement = ________________

8. Determine the circuit phase angle and record in table 2.
   
   \[
   \text{Phase Angle} = \frac{\text{Time Displacement}}{\text{Periodic Time}} \times 360 = \quad \text{______________}
   \]

9. From the waveforms displayed on the CRO complete the following statement -
   
   The circuit current (leads/lags) ________________ the supply voltage.

10. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 2**

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

11. Switch off the supply, then disconnect the circuit.

12. Return all equipment to its proper place, safely and carefully.
3. **OBSERVATIONS:**

1. Draw the phasor diagram for the R-L circuit of figure 1.
   
   Scales: $1\text{mm} = 0.5\text{mA}$ and $1\text{mm} = 0.3\text{V}$
   
   Use the following procedure -
   (a) draw the current to scale on the horizontal as a reference
   (b) draw the resistor voltage drop to scale in phase with the current
   (c) draw the supply voltage to scale at the angle as determined from the CRO
   (d) draw a phasor to represent the ballast voltage drop, between the tip of the supply voltage phasor and the tip of the resistor voltage drop phasor.

2. From the phasor diagram determine the value of the voltage drop across the ballast.
   
   Ballast voltage drop = ________________

3. From the phasor diagram, determine the angle of phase difference between the voltage drop across the ballast and the circuit current.

   Ballast phase angle = ________________
4. Compare the measured value of voltage drop across the ballast with the value determined from the phasor diagram.

5. Explain why the ballast phase angle was less than 90°.

6. Draw the phasor diagram for the R-C circuit of figure 2. Use scales and method similar to that used for the R-L circuit.

7. From the phasor diagram determine the value of the voltage drop across the capacitor.
   \[\text{Capacitor voltage drop} = \text{___________________________}\]

8. From the phasor diagram, determine the angle of phase difference between the voltage drop across the capacitor and the circuit current.
   \[\text{Capacitor phase angle} = \text{___________________________}\]
9. Compare the measured value of voltage drop across the capacitor with the value
determined from the phasor diagram.

10. Explain how this practical segment verifies the total voltage applied to a series AC circuit
is equal to the phasor sum of the individual voltage drops in the circuit.

********************************************
Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The phase angle (\( \phi \)) between voltage and current in an R.L. series circuit is between:
   (a) 0\(^{\circ}\) and 90\(^{\circ}\) lagging.
   (b) 0\(^{\circ}\) and 90\(^{\circ}\) leading.
   (c) 90\(^{\circ}\) and 180\(^{\circ}\) lagging.
   (d) 90\(^{\circ}\) and 180\(^{\circ}\) leading.

2. Adding extra inductance to an R.L. series circuit will cause the phase angle (\( \phi \)) between voltage and current to:
   (a) remain unchanged.
   (b) increase.
   (c) become maximum.
   (d) decrease.

3. The opposition to current flow in any ac circuit containing ______ and reactive components is known as ______ and is measured in ohms.
   (a) capacitive, reactance
   (b) inductive, reactance
   (c) resistive, impedance
   (d) inductive, impedance

4. Adding extra resistance to an R.C. series circuit will cause the phase angle (\( \phi \)) between voltage and current to:
   (a) remain unchanged.
   (b) increase.
   (c) become maximum.
   (d) decrease.
5. If the inductive reactance and resistance of an R.L. series circuit are equal, the circuit phase angle will be:
   (a) 45° lead
   (b) 45° lag
   (c) 30° lead
   (d) 60° lag

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. To decrease the phase angle in an R.L. series circuit, either ___(a)___ the circuit resistance, or ___(b)___ the circuit inductance.

7. In an impedance triangle for an R.L. series circuit, the circuit resistance is ___(a)___ with the reference, the circuit ___(b)___ will ___(c)___ the reference, whilst the circuit impedance is the ___(d)___.

8. The circuit phase angle for an R.C. circuit is between ___(a)___ and ___(b)___, and the current will ___(c)___ the voltage.

9. To increase the phase angle in an R.C. series circuit, either ___(a)___ the circuit resistance, or ___(b)___ the circuit ___(c)___.

10. Increasing the supply frequency to an R.L. series circuit will cause the circuit phase angle to ______.

11. Decreasing the supply frequency to an R.C. series circuit will cause the circuit phase angle to ______.

12. When using an impedance triangle to solve for series R.L or R.C circuits, the phase angle is measured between the circuit ___(a)___ and the circuit ___(b)___.

SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

13. Determine the impedance of a series R.L circuit consisting of a 220Ω resistor and a 1.59H ideal inductor when connected to a 240V, 50Hz supply. (546Ω)

14. If a 120Ω resistor is connected in series with 0.75H ideal inductor, determine how much current will flow if connected to a 415V, 50Hz supply. (1.57A)
15. Determine the impedance if the 220Ω resistor of Q12 is now connected in series with a 22μF capacitor when connected to a 240V, 50Hz supply. (263Ω)

16. A 560Ω resistor is connected in series with a 5.68μF capacitor. Determine the current flowing in this circuit if connected to a 240V, 50Hz supply. (303mA)

17. An R.L. series circuit draws 0.333A when connected to a 32V, 50Hz supply. Determine the value of the circuits resistance and inductance if the circuit phase angle is measured to be 60° lag. (R=48Ω; L=265mH)

18. When connected to a 200V, 400Hz supply, an R.C. series circuit draws 2A. If the circuit phase angle is found to be 45°, determine the value of the circuits resistance and capacitance. (R=70.7Ω; C=5.6μF)

19. When connected to a 50Hz supply, an R.L. series circuit draws 0.4A. If the voltage drop across the resistor is 16V, and the voltage drop across the ideal inductor is 12V, determine:
   (a) the voltage applied to the circuit by phasor diagram using a scale of 1mm = 0.2V; (20V)
   (b) the circuit phase angle. (37° lag)
   (c) the resistance of the resistor; (40Ω)
   (d) the reactance of the inductor; (30Ω)
   (e) the circuit impedance; (50Ω)
   (f) the inductance of the inductor; (95.5mH)
   (g) the minimum power rating for the resistor. (6.4W)

20. When connected to a 50Hz supply, an 80Ω resistor connected in series with a 33μF capacitor draws a current of 2A. Determine by phasor diagram the voltage applied to the circuit and the circuit phase angle using a scale of 1mm = 2V. (250V; φ = 50° lead)
SERIES R-L-C CIRCUITS

PURPOSE:

To develop an understanding of the characteristics of R-L-C series AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- determine values of voltage, current and impedance associated with R-L-C series circuits given resistance, inductance, capacitance and supply voltage.
- determine the phase angle for series R-L-C circuits, by calculation or phasor diagram.
- describe the conditions in a series R-L-C circuit that produce resonance and state that at resonance the:
  - impedance is a minimum
  - impedance equals resistance
  - current is a maximum
  - circuit phase angle is 0º.
- calculate the resonant frequency of a series R-L-C circuit.

REFERENCES:

Pages 179-181, 189-191.
1. SERIES R-L-C CIRCUIT

Consider a series AC circuit containing resistance, inductance and capacitance as shown in figure 1.

![Figure 1](image1)

Applying the rules of series circuits, it can be said the supply voltage is equal to the phasor sum of the circuit voltage drops.

![Figure 2](image2)

If it is assumed the inductive reactance is greater than the capacitive reactance, the phasor diagram for the circuit would be as shown in figure 2.

![Figure 3](image3)

On the other hand, if it is assumed the capacitive reactance is greater than the inductive reactance, the phasor diagram for the circuit would be as shown in figure 3.

It should be noted that if the -

- inductive reactance (\(X_L\)) is greater than the capacitive reactance (\(X_C\)), the current \(\phi\) the supply voltage by the angle \(\phi\).

- capacitive reactance (\(X_C\)) is greater than the inductive reactance (\(X_L\)), the current \(\phi\) the supply voltage by the angle \(\phi\).
If a series circuit contains both inductive and capacitive reactance, their effects tend to cancel each other.

2. IMPEDANCE TRIANGLE FOR AN R-L-C SERIES CIRCUIT

The voltage triangle shown in figure 4 is obtained from the phasor diagram of figure 2.

![Figure 4](image)

![Figure 5](image)

The voltage triangle shown in figure 5 is obtained from the phasor diagram of figure 3.

Dividing each side of the voltage triangles by the current (I) gives what is known as Fleming's impedance triangle for the R-L-C series circuit. See figures 6 and 7.

![Figure 6](image)

![Figure 7](image)

By applying the Pythagorean Theorem to the geometry of these triangles, allows the impedance of the circuit to be determined -

\[ Z = \sqrt{R^2 + (X_L - X_C)^2} \]

where:
- \( Z \) = circuit impedance in ohms
- \( R \) = resistance in ohms
- \( X_L \) = inductive reactance in ohms
- \( X_C \) = capacitive reactance in ohms
The application of basic trigonometry to the impedance triangles of figures 6 and 7 allows the determination of the circuit phase angle.

Example: 1.
A circuit consists of a resistance of 80\(\Omega\) in series with an inductive reactance of 130\(\Omega\) and a capacitive reactance of 70\(\Omega\). If the voltage applied to the circuit is 400V at 50Hz, calculate the -
(a) circuit impedance
(b) circuit current
(c) voltage drop across each component
(d) angle of phase difference.

\[ R = 80 \Omega \]
\[ L = 130 \Omega \]
\[ C = 70 \Omega \]

\[ 400V, 50Hz \]

Figure 8
Example: 2

A 240V, 50Hz series circuit consists of a resistor, practical inductor and a capacitor as shown in figure 9. Determine -
(a) impedance
(b) current
(c) phase angle

3. CIRCUIT VOLTAGE DROPS

The voltage drops across individual components in a series R-L-C circuit may be higher than the supply voltage, in some cases much much higher. These very high component voltage drops can -

• prove dangerous to life
• damage equipment
• damage insulation.
Example: 3

For the circuit shown in figure 10, determine -

(a) voltage drops across each component

(b) using a phasor diagram, the supply voltage and circuit phase angle.

Scale: 1mm = 2V
4. SERIES RESONANCE

Consider a series R-L-C circuit to which a variable frequency AC supply is applied. As the supply frequency is increased -

- the inductive reactance of the inductor will _________________________
- the capacitive reactance of the capacitor will ________________________.

This concept is illustrated in figure 11.

![Figure 11](image)

From figure 11 it can be seen that a one particular frequency, the reactance's of the inductor and capacitor are equal.

This frequency is known as the ______________________________ of the circuit.

Therefore, a series AC circuit containing resistance, inductance and capacitance is in a state of resonance, when

the inductive reactance \( (X_L) \) equals the capacitive reactance \( (X_C) \),

that is, when the resultant reactance \( (X_L - X_C) \) is zero.

Since impedance \( Z = \sqrt{R^2 + (X_L - X_C)^2} \), for the circuit under consideration, then at resonance,

that is, the impedance is equal to the resistance of the circuit.
Thus, when a series AC circuit is in a state of resonance, the only factor limiting the current in the circuit is its resistance, hence the current will be a maximum for a constant applied voltage.

As stated, the frequency at which resonance occurs is known as the resonant frequency. If the inductance and capacitance of a circuit are known, the resonant frequency can be determined as follows -

\[
\text{where: } f_R = \text{resonant frequency in hertz} \\
L = \text{inductance in henries} \\
C = \text{capacitance in farads}
\]

**Example: 4**

An inductor having a resistance of 25Ω and an inductance of 0.2H is connected in series with a 100µF capacitor. Determine the resonant frequency of the circuit.

Summarising the conditions that apply in a series R-L-C circuit at resonance -

- impedance (Z) equals Resistance (R) as the inductive reactance (\(X_L\)) ____________ the capacitive reactance (\(X_C\))
- current is limited by only _______________
- current is a _______________
- circuit phase angle = _______________.

The property of resonance is used in radio work to tune to a signal of a certain frequency.

Now, since resonant frequency is expressed by the equation:

\[
fo = \frac{1}{2\pi\sqrt{LC}}
\]

a circuit can be tuned to resonance at different frequencies by means of a variable inductance or by varying the capacitance with a variable capacitor. The latter method is more commonly used.
Other situations where resonance, or near resonance, can occur -

- a lightly loaded, long overhead transmission line - the voltage at the end of the line is greater than the voltage at the start of the line.
- a transformer supplied by a long underground cable - when energised can be a resonant circuit, with high voltages developed across the transformer and cable.

At resonance, the voltages across an inductor and a capacitor may attain values much higher than that of the applied voltage. These high values of voltages are liable to be dangerous and may break down the insulation of the inductor or capacitor. The current in low resistance circuits may also attain excessive values at resonance and cause damage due to overheating. However, these remarks only apply to power circuits: in radio work, the relatively small currents obtained do not, generally, produce dangerous voltages across the circuit components.

Example: 5

An inductor having a resistance of 15Ω and an inductance of 1H is connected in series with a 10µF capacitor to a 240V, 50Hz supply. Calculate the -

(a) resonant frequency
(b) current at resonance
(c) voltage drop across each component at resonance.

*******************
R-L-C SERIES CIRCUIT

PURPOSE:

This practical assignment will be used to examine the characteristics of R-L-C series AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

• Connect a series R-L-C AC circuit.
• Measure voltages and currents associated with R-L-C series AC circuits.
• Construct phasor diagrams from results obtained by measurement.
• Verify the voltage applied to a series AC circuit is equal to the phasor sum of the circuit voltage drops.

EQUIPMENT:

☐ 1 x variable, single phase AC supply at 50Hz
☐ 1 x R-L-C panel
☐ 2 x digital multimeters
☐ 1 x AC current clamp
☐ 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.
The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. R-L-C SERIES CIRCUIT

1. Connect the circuit shown in figure 1.

![Circuit Diagram]

2. Switch on the power supply and adjust to give an applied voltage 10V, as indicated by the digital multimeter.

3. Using the digital multimeter measure the voltage drops across the ballast and the capacitor. Record the values in table 1.

<table>
<thead>
<tr>
<th>Supply Voltage volts</th>
<th>Ballast Voltage Drop volts</th>
<th>Capacitor Voltage Drop volts</th>
<th>Circuit Current mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>10V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Using the AC current clamp, measure the circuit current. Record in table 1.

5. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

6. Switch off the supply.
7. Reconnect the circuit shown in figure 2. Note, the overall capacitance of 5.5µF is made up of a 2.2µF capacitor in parallel with a 3.3µF capacitor.

![Circuit Diagram](image)

**Figure 2**

8. Switch on the power supply and adjust to give an applied voltage 10V, as indicated by the digital multimeter.

9. Using the digital multimeter measure the voltage drops across the ballast and the capacitor. Record the values in table 2.

<table>
<thead>
<tr>
<th>Supply Voltage volts</th>
<th>Ballast Voltage Drop volts</th>
<th>Capacitor Voltage Drop volts</th>
<th>Circuit Current mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>10V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Using the AC current clamp, measure the circuit current. Record in table 2.

11. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

12. Switch off the supply, then disconnect the circuit.

13. Return all equipment to its proper place, safely and carefully.
2. OBSERVATIONS:

1. Draw the phasor diagram for the R-L-C circuit of figure 1.
   Scales: 1mm = 0.5mA and 1mm = 0.3V
   Use the following procedure -
   (a) draw the current to scale on the horizontal as a reference
   (b) draw the capacitor voltage drop to scale, lagging the current by 90°
   (c) set the radius of your compass to represent to scale the applied voltage
   (d) place the point of the compass at the origin of the diagram and scribe an arc
   (e) set the radius of your compass to scale to represent the voltage drop across the ballast
   (f) place the point of the compass at the tip of the capacitor voltage drop phasor and scribe an arc which intersects the arc previously drawn
   (g) draw the phasors to represent the applied voltage and the ballast voltage drop
   (h) using a protractor measure the phase angles $\phi_r$ and $\phi_L$ from the diagram.

2. From the phasor diagram determine the value of the circuit phase angle $\phi_r$.

   Circuit phase angle, $\phi_r = \:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\:\\

   Scales: \(1\text{mm} = 2\text{mA}\) and \(1\text{mm} = 1\text{V}\).

   Use a procedure similar to that described in question 1.

5. From the phasor diagram determine the value of the circuit phase angle \(\phi_r\).
   
   Circuit phase angle, \(\phi_r = \) __________

6. From the phasor diagram, determine the value of the ballast phase angle \(\phi_L\).
   
   Ballast phase angle, \(\phi_L = \) __________

7. Calculate the impedance of the circuit when -
   
   (a) \(C = 3.3\mu\text{F}\)
   
   (b) \(C = 5.5\mu\text{F}\).  (Show all working)
8. Briefly explain, in terms of voltages, current, impedance and phase angle, what would occur if the capacitor used in figure 1 was changed to one with a value which caused resonance to occur.

9. Which value of capacitance, 3.3\(\mu\)F or 5.5\(\mu\)F, caused the circuit to be closest to resonance? Give reasons for your answer.
Series R.L.C Circuits

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. If the circuit phase angle in an R.L.C. series circuit is between 0° and 90° lagging, then the _____ is higher than the _____.
   (a) capacitive reactance, inductive reactance
   (b) inductive reactance, capacitive reactance
   (c) capacitive reactance, impedance
   (d) inductive reactance, impedance

2. Adding extra capacitance to an R.L.C. series circuit with a lagging phase angle will cause the circuit phase angle to:
   (a) remain unchanged.
   (b) increase.
   (c) become maximum.
   (d) decrease.

3. To determine the impedance of a series R.L.C. circuit, you would use:
   (a) \( Z = \sqrt{R^2 + (X_L - X_C)^2} \) Ω
   (b) \( Z = R^2 + X_L^2 - X_C^2 \) Ω
   (c) \( Z = \sqrt{R^2 + (X_L + X_C)^2} \) Ω
   (d) \( Z = \sqrt{R^2 + X_L^2 - X_C^2} \) Ω
4. Series resonance occurs when:
   (a) \( X_L = Z \)
   (b) \( X_C = Z \)
   (c) \( X_L = X_C \)
   (d) \( X_L + X_C = R \)

5. As the voltage drops in a series R.L.C. circuit are _____, they are added by ______.
   (a) out of phase, phasor addition
   (b) in phase, phasor addition
   (c) out of phase, numerical addition
   (d) in phase, numerical addition

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. To decrease the phase angle in a series R.L.C. circuit, either ___(a)___ the circuit effective reactance, or ___(b)___ the circuit resistance.

7. At series resonance, the circuit impedance is a ___(a)___ value, and the circuit current is a ___(b)___ value.

8. If resonance occurs in a power series R.L.C. circuit, the ___(a)___ across the reactive components can become ___(b)___.

9. Increasing the supply frequency to a series R.L.C. circuit with a leading phase angle will cause the inductive reactance to ___(a)___, the capacitive reactance to ___(b)___, and the circuit phase angle to ___(c)___.

10. Decreasing the supply frequency to a lagging R.L.C. series circuit will cause the circuit phase angle to ______.

11. When a series circuit is operating at resonant frequency, ___(a)___ reactance equals ___(b)___, and impedance equals ___(b)___, and the circuit current is ___(c)___

SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

12. A 27Ω resistor is connected in series with a 250mH inductor and a 33µF capacitor. If connected to a 50Hz supply, determine the impedance of the circuit. (32.4Ω)

13. Determine the supply current if a 50Ω resistor is connected in series with an inductor with a reactance of 60Ω and a capacitor with a reactance of 80Ω when connected to a 240V, 50Hz supply. (4.46A)
14. A 200mH inductor is connected in series with a 100μF capacitor and an unknown resistor. Determine the value of the unknown resistor if the circuit draws 5A when connected to a 240V, 50Hz supply. (36.6Ω)

15. For the circuit of figure 1, determine the:
   (a) reactance of the inductor (235.6Ω)
   (b) reactance of the capacitor (159Ω)
   (c) impedance of the circuit (280.6Ω)
   (d) current flowing in the circuit (1.48A)
   (e) voltage drop across the inductor (348V)
   (f) voltage drop across the capacitor (235V)
   (g) voltage drop across the resistor (399V)
   (h) circuit phase angle (15.8° lag)

16. If the circuit of figure is connected to a variable frequency power supply, determine the resonant frequency of the circuit. (41Hz)

17. When connected to a 50Hz supply, an 560Ω resistor connected in series with a 2.71H ideal inductor and a 5μF capacitor draws a current of 400mA. Determine by phasor diagram the voltage applied to the circuit and the circuit phase angle using a scale of 1mm = 2V. (240V; 21° lag)
PARALLEL AC CIRCUITS

PURPOSE:

To develop an understanding of the characteristics of parallel and series-parallel AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- determine values of voltage, current and impedance associated with parallel and series-parallel AC circuits.
- use phasor diagrams to illustrate phase relationships and determine values associated with parallel AC circuits.
- determine the phase angle for parallel and series-parallel AC circuits.
- describe the conditions in a parallel AC circuit that produce resonance and state that at resonance:
  - impedance is a maximum
  - impedance equals resistance
  - current is a minimum
  - circuit phase angle is 0º.

REFERENCES:

Pages 181-183, 191-192.
1. INTRODUCTION

The majority of practical circuits consist of loads connected in parallel. For example:
- lighting circuits
- power circuits
- homes
- substations.

2. CIRCUIT CURRENT

Figure 1 shows a parallel circuit consisting of two impedances.

\[
\begin{align*}
V & \quad Z_1 \quad Z_2 \\
I_1 & \quad I_2 \\
\text{IT} &
\end{align*}
\]

Figure 1

Applying the rules of parallel circuits, it can be said the supply current is equal to the phasor sum of the branch currents.

For the circuit of figure 1, assume the -
- current \( I_1 \) lags the voltage by 20º
- current \( I_2 \) lags the voltage by 45º.

Under these conditions the phasor diagram that represents the phase relationships within the circuit would be:

\[
\begin{align*}
\text{V} & \quad I_1 \quad \text{Z}_1 \quad \text{Z}_2 \\
\text{IT} &
\end{align*}
\]

Figure 2

As stated, if the values and phase angles of the branch currents are known, the supply current may be determined.
The procedure for determining values associated with parallel or series-parallel AC circuits are as follows -

1. determine the impedance of each branch:

2. determine each branch current:

3. determine each branch phase angle:

4. determine the supply current by phasor addition of the branch currents:

5. from the phasor diagram, measure the circuit phase angle:

6. determine overall circuit impedance:
Example: 1.
A 240V, 50Hz circuit consists of a 60Ω heater in parallel with a fan motor which has a resistance of 120Ω and an inductive reactance of 160Ω. Determine the -
(a) impedance of each branch
(b) current in each branch
(c) phase angle of each branch
(d) supply current
(e) circuit phase angle
(f) circuit impedance.
Scale: 1mm = 0.04A
Example: 2
An industrial oven with a resistance of 20Ω is connected in parallel with a welder which has a resistance of 15Ω and an inductive reactance of 20Ω. If the supply is 240V at 50Hz, determine the -

(a) welder impedance
(b) welder current and phase angle
(c) oven current and phase angle
(d) total circuit current and phase angle
(e) circuit impedance.

Scale: 1mm = 0.1A

Figure 5
**Example: 3**

A single phase motor draws 6A at a phase angle of 32º lag from a 240V, 50Hz supply. A 20µF capacitor is connected in parallel with the motor. Determine the -

(a) capacitor current and phase angle

(b) supply current

(c) circuit phase angle

(d) circuit impedance

Scale: 1mm = 0.06A

Figure 6
Example: 4
If the 20\(\mu\)F capacitor in the circuit of example 3 was replaced with a 40\(\mu\)F capacitor, determine the -
(a) capacitor current and phase angle
(b) supply current
(c) circuit phase angle
(d) circuit impedance
Scale: 1mm = 0.06A

Figure 7
Example: 5

A single phase 240V, 50Hz installation consists of the following parallel connected loads -

- a heater with a resistance of 40Ω
- a single phase motor with a resistance of 25Ω and an inductance of 0.1H
- a 40µF capacitor.

Determine the -

(a) circuit current
(b) circuit phase angle
(c) circuit impedance.

Scale: 1mm = 0.06A

Figure 8
3. **PARALLEL RESONANCE**

Consider a parallel R-L-C circuit to which a variable frequency AC supply is applied.

![Figure 9](image)

As the supply frequency is increased -
- the inductive reactance of the inductor will ________
- the capacitive reactance of the capacitor will ________

This concept is illustrated in figure 10.

![Figure 10](image)

From figure 10 it can be seen that at a particular frequency, the reactance's of the inductor and capacitor are equal.

This frequency is known as the ______ of the circuit.

Therefore, a parallel AC circuit containing resistance, inductance and capacitance is in a state of resonance, when

\[
\text{the inductive reactance (}X_L\text{) equals the capacitive reactance (}X_C\text{),}
\]

that is, when the resultant reactance \((X_L - X_C)\) is zero.

At resonance the inductive current effectively cancels the capacitive current.
Therefore the supply current must be a _________________.

If the supply current is a minimum, the circuit impedance must be a _________________.

As the reactance's cancel one another at resonance, the only opposition to the flow of current is the circuit resistance.

As a result, the circuit current must be ________________ with the applied voltage.

Therefore, the circuit phase angle must be _________________.

In practice, a parallel resonant circuit would be as shown in figure 11.

At resonance, energy is transferred back and forth from the magnetic field of the inductor to the electrostatic field of the capacitor.

The supply current flows to replace the losses incurred when the circulating current flows through the resistance of the inductor.

The circulating current flowing between the inductor and capacitor can be very large. In fact, much much larger than the supply current.
PARALLEL AC CIRCUIT

PURPOSE:

This practical assignment will be used to examine the characteristics of parallel AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect parallel AC circuits.
- Measure voltages and currents associated with parallel AC circuits.
- Construct phasor diagrams from results obtained by measurement.
- Verify the current supplied to a parallel AC circuit is equal to the phasor sum of the circuit branch currents.
- Determine the total impedance of parallel AC circuits.
- Describe the effects of parallel resonance.

EQUIPMENT:

- 1 x variable, single phase AC supply at 50Hz
- 1 x R-L-C panel
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. PARALLEL R-C CIRCUIT

   1. Connect the R-C circuit shown in figure 1.

   ![Figure 1](image)

   2. Switch on the power supply and adjust to give an applied voltage 25V, as indicated by the digital multimeter.

   3. Using the AC current clamp measure the supply current and the two branch currents. Record the values in table 1.

   **Table 1**
   
<table>
<thead>
<tr>
<th>Supply Voltage volts</th>
<th>Supply Current mA</th>
<th>Resistor Current mA</th>
<th>Capacitor Current mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>25V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   4. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 1**
   
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

   5. Switch off the supply.
2. PARALLEL R-L CIRCUIT

1. Connect the R-L circuit shown in figure 2.

![R-L Circuit Diagram]

Figure 2

2. Switch on the power supply and adjust to give an applied voltage 25V, as indicated by the digital multimeter.

3. Using the AC current clamp measure the supply current and the two branch currents. Record the values in table 2.

Table 2

<table>
<thead>
<tr>
<th>Supply Voltage (volts)</th>
<th>Supply Current (mA)</th>
<th>Resistor Current (mA)</th>
<th>Ballast Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

5. Switch off the supply.
3. **PARALLEL L-C CIRCUIT**

1. Connect the L-C circuit shown in figure 3.

2. Switch on the power supply and adjust to give an applied voltage 25V, as indicated by the digital multimeter.

3. Using the AC current clamp measure the supply current and the two branch currents. Record the values in table 3.

4. **Do not proceed** until the teacher checks your results and completes the progress table.

5. Switch off the supply, then disconnect the circuit.

6. Return all equipment to its proper place, safely and carefully.
4. **OBSERVATIONS:**

1. Draw the phasor diagram for the R-C circuit of figure 1.
   
   Assume $\phi_R = 0^\circ$ and $\phi_C = 90^\circ$.
   
   Scales: 1mm = 0.5mA and 1mm = 0.15V

2. From the phasor diagram determine the value of the circuit current.

   Circuit current = ______________

3. From the phasor diagram, determine the value of the circuit phase angle $\phi$.

   Circuit phase angle, $\phi =$ ______________

4. Determine the impedance of the R-C circuit shown in figure 1.
Scales: 1mm = 0.5mA and 1mm = 0.15V.
Use the following procedure -
(a) draw the voltage to scale on the horizontal as a reference
(b) draw the resistor current to scale, in phase with the voltage
(c) set the radius of your compass to represent to scale the supply current
(d) place the point of the compass at the origin of the diagram and scribe an arc
(e) set the radius of your compass to scale to represent the ballast current
(f) place the point of the compass at the tip of the resistor current phasor and scribe an arc which intersects the arc previously drawn
(g) draw the phasors to represent the supply current and the ballast current
(h) using a protractor measure the phase angles $\phi$ and $\phi_L$ from the diagram.

6. From the phasor diagram determine the value of the circuit current

Circuit current = ______________

7. From the phasor diagram determine the value of the circuit phase angle $\phi$.

Circuit phase angle, $\phi$ = ______________

8. From the phasor diagram, determine the value of the ballast phase angle $\phi_L$.

Ballast phase angle, $\phi_L$ = ______________
9. Calculate the impedance of the R-L circuit shown in figure 2.

10. Based on the results obtained by measurement and from the phasor diagrams, is it true to say the supply current to a parallel AC circuit is equal to the sum of the branch currents?

11. Based on your results, what is the effect on overall circuit impedance of connecting impedances in parallel?

12. Draw the phasor diagram for the L-C circuit of figure 3.
   Assume $\phi_C = 90^\circ$.
   Scales: 1mm = 0.5mA and 1mm = 0.15V.
13. From the phasor diagram determine the value of the circuit current.

Circuit current = ______________

14. From the phasor diagram determine the value of the circuit phase angle $\phi$.

Circuit phase angle, $\phi = ______________$

15. Calculate the impedance of the circuit shown in figure 3.

.................................................................

16. Briefly give the reason for the impedance of the parallel L-C circuit being so high.

.................................................................

17. Explain why the currents in the branches of the L-C circuit were so much higher than the supply current.

.................................................................
Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The phase angle \((\phi)\) between voltage and current in an R.C. parallel circuit is between:
   (a) 0° and 90° lagging.
   (b) 0° and 90° leading.
   (c) 90° and 180° lagging.
   (d) 90° and 180° leading.

2. Adding extra inductance to an R.L. parallel circuit will cause the phase angle \((\phi)\) between voltage and current to:
   (a) remain unchanged.
   (b) increase.
   (c) become maximum.
   (d) decrease.

3. In a parallel resonant circuit, circuit impedance is a ______, and circuit current is a ______.
   (a) maximum, maximum
   (b) minimum, minimum
   (c) maximum, minimum
   (d) minimum, maximum

4. Adding extra capacitance to a leading R.L.C. parallel circuit will cause the phase angle \((\phi)\) between voltage and current to:
   (a) remain unchanged.
   (b) increase.
   (c) become maximum.
   (d) decrease.
5. In a parallel L.C. circuit, the component with the largest _____ will determine the phase angle for the circuit.
   (a) current  
   (b) voltage  
   (c) reactance  
   (d) resistance

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

6. To decrease the phase angle in an R.L. parallel circuit, either (a)___ the circuit resistance, or (b)___ the circuit inductance.

7. Increasing the frequency of the supply to an R.L.C. parallel circuit will cause the resistive current to (a)___, the inductive current to (b)___ and the capacitive current to (c)___

8. The circuit phase angle for an R.L. parallel circuit is between (a)___ and (b)___, and the current will (c)___ the voltage.

9. To increase the phase angle in an R.C. parallel circuit, either (a)___ the circuit resistance, or (b)___ the circuit (c)___.

10. Increasing the supply frequency to an R.L. parallel circuit will cause the circuit phase angle to _____.

11. Decreasing the supply frequency to an R.C. parallel circuit will cause the circuit phase angle to _____.

12. At parallel resonance, the circulating (a)___ between the reactive components can be (b)___
SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple. Any question solved by phasor diagram should be drawn accurately to scale on 5mm graph paper attached to your solution.

13. For the circuit of figure 1, if the capacitive reactance is 25Ω, the inductive reactance is 30Ω and the resistance is 10Ω, determine:
   (a) the impedance, current and phase angle for the capacitive branch; (25Ω, 8A, 90° lead)
   (b) the impedance, current and phase angle for the inductive branch; (31.6Ω, 6.33A, 71.5° lag)
   (c) the supply current and circuit phase angle; (2.83A, 45° lead) (1mm = 0.1A)
   (d) the circuit impedance. (70.6Ω)

14. For the circuit of figure 1, if the capacitor is 25µF, the inductor is 250mH and the resistance is 15Ω, determine:
   (a) the capacitive current and phase angle; (1.57A, 90° lead)
   (b) the inductive current and phase angle; (2.5A, 79° lag)
   (c) the supply current and circuit phase angle; (1A, 61.6° lag) (1mm = 25mA)
   (d) the circuit impedance (200Ω)

15. If a 120Ω resistor is connected in parallel with 382mH inductor with a resistance of 35Ω, determine how much current will flow if connected to a 415V, 50Hz supply. (5.4A) (1mm = 50mA)

16. An L.C. parallel circuit is connected to a single phase 240V, 50Hz supply. If the current through the capacitor 12A, and the current through the inductor is 16A at a phase angle of 60° lagging, determine the:
   (a) impedance of the inductor; (15Ω)
   (b) resistance of the inductor; (7.5Ω)
   (c) impedance of the capacitor; (20Ω)
   (d) current drawn from the supply; (8.2A) (1mm = 0.2A)
   (e) circuit phase angle. (13.1°lag)
   (f) circuit impedance; (29.3Ω)

17. An 80Ω resistor connected in parallel with a 33µF capacitor is connected to a 250V, 50Hz supply. Determine by phasor diagram the current drawn from the supply and the circuit phase angle using a scale of 1mm = 0.05A. (4A; φ = 40° lead)