Experiment 17 - Experimental Error Analysis

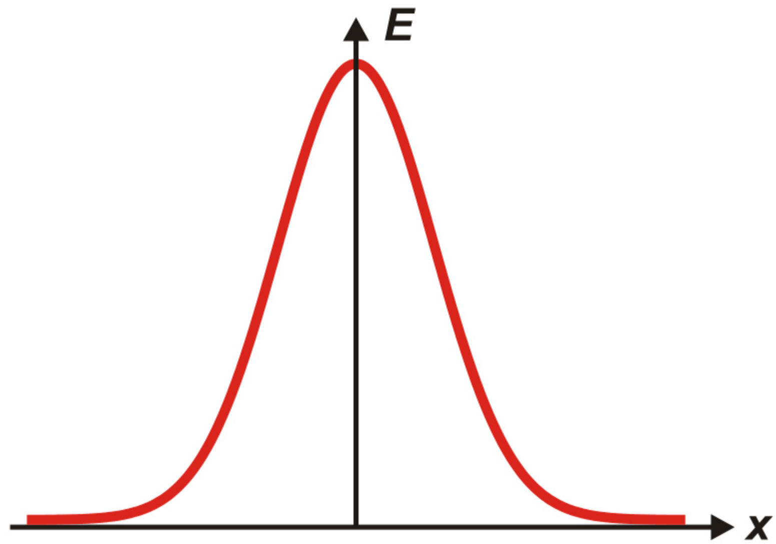
Department of Electrical Engineering & Electronics

September 2019, Ver. 4.1

Experiment specifications

Module(s)	ELEC222 / ELEC224 / ELEC273
Experiment code	17
Semester	1
Level	2
Lab location	Electronics lab, third floor/fourth floor, check the timetable
Work	In groups
Timetabled time	3 hrs
Subject(s) of relevance	Transistor amplifier circuits, Error analysis
Assessment method	Formal report. One lab report per person following the guidelines set out in the "How to write a good lab report" handout (available in VITAL).
Submission deadline	On Friday midnight, 7 days after the date of the laboratory, submitted in Microsoft Word or PDF format via VITAL only.

Important: Marking of all coursework is anonymous. Do not include your name, student ID number, group number, email or any other personal information in your report or in the name of the file submitted via VITAL. A penalty will be applied to submissions that do not meet this requirement.



Instructions:

- **Read this script carefully before attempting the experiment. Check VITAL for more resources (Learning Resources→Supporting Material folder).**
- **The Pre-Lab Questions should be answered before the lab day. They are available on VITAL (Online) and worth 10% of the overall mark of the experiment.**
- **Keep a record of all measurements taken, comments made and of graphs plotted in a logbook.**
- **As you complete each part of the experiment, ensure that your results (readings, plots, calculations) are viewed and approved by one of the demonstrators before proceeding. Include your signed results in your final report.**
- **If you have problems, consult Appendix A (Common problems) of this script before asking a demonstrator.**
- **If you use data or work from other sources be sure to reference them.**
- **If you have any feedback on your laboratory experience today, please write it down on the last page of this script.**

1 Learning outcomes

At the end of this lab, you will be:

- familiar with the types of errors, their sources, the ways to reduce them and how to report uncertainty.
- able to build a common emitter amplifier circuit, test its DC bias settings and amplify AC signals.

2 Introduction - Error in experiments

Most laboratory practical experiments involve the following:

- Making some measurements of physical quantities,
- Calculating some useful values from them, and
- Comparing with expected values.

No measurement of any physical quantity is ever perfectly accurate. The discrepancy between the measured value and the true value of the quantity may arise from different sources. No matter how much effort is put into refinement of technique or into improvement of the instruments, the error can only be decreased in magnitude but never eliminated entirely. The statement of the result of a measurement is not complete without an indication of how much error the measurement might contain. This information is called **measurement uncertainty**. To obtain an experimental result with an estimate of its uncertainty, you need to know the types of errors, the ways to reduce the errors, and how to treat the data properly [1].

2.1 What is an error?

An error in a measurement result is the difference between the result itself and the true value of the measured quantity. It can come from the limitations of the measuring equipment or from external sources. Errors can be minimised by choosing an appropriate method of measurement, but they can not be eliminated.

2.2 Types of error

There are two types of errors: systematic and random [1,2].

- **Systematic errors** affect the measurement results always in the same way. They usually arise from the instrument itself (e.g., an offset). These errors can be corrected if they are detected. This procedure is called **instrument calibration**. Systematic errors are often the reason why the result you obtain from your measurement is not consistent with the expected value.

  Suppose, for example, you use a magnifier to read a ruler more accurately. You could certainly read to 1 mm quite well in this way. But what if the ruler is one of those cheaply made plastic ones - how well do its markings actually represent real millimeters? Such rulers may be wrong by about 0.5 mm or even 1 mm along a 300 mm ruler, when compared with a high quality scale. All measuring instruments have an error at some level. The maximum error is usually stated by the manufacturer and is called **accuracy**. For example, some of the digital multimeters in the laboratory have a quoted accuracy of 0.5% of the reading.

  The readings you make are usually limited to a certain number of significant digits. For a ruler, the reason for this limit is obvious. In the case of instruments with a digital readout, it depends on the number of digits displayed and for analogue instruments on the number of divisions indicated. The smallest amount by which the quantity may vary before you can actually detect this change is termed the **resolution** of the instrument. The maximum error due to the resolution is generally accepted to be half the smallest division.

- **Random errors** result from unknown and unpredictable variations in the experimental situation. Unpredictable fluctuations in temperature or in-line voltage are examples of sources of random errors. These can also be referred to as accidental errors and can be the result also of poor experimental technique, oversight, and human error. Random errors can be reduced by repeating the measurement a sufficient number of times and averaging the results, or by improving the experimental technique. Random errors are susceptible to mathematical treatment.

2.3 Accuracy and precision

In experimental measurements, there is an important distinction between accuracy and precision. The accuracy of a measurement signifies how close it comes to the true value, i.e., how correct it is. For example, if one arrow hits exactly in the centre of the target, it is highly accurate.

On the other hand, the precision refers to the agreement among repeated measurements, i.e., the "spread" of the measurements, or how close together they are. For example, if six arrows hit within one centimetre of each other at one side of the target, the shooting is highly precise but not accurate.

High precision does not necessarily imply high accuracy, but high precision is necessary to obtain high accuracy, unless several measurements are averaged. Figure 1 illustrates the concept of accuracy and precision.

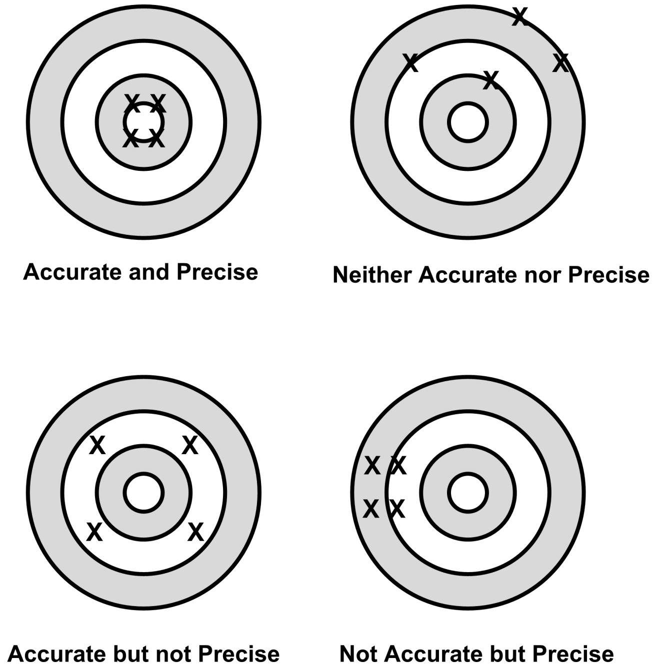


Figure 1: Illustration of accuracy and precision [2]

2.4 Errors and uncertainty

The definition of error (i.e., the difference between the measured value and the true value) relies on the knowledge of the "true value". However, since every measurement is always affected by some errors, the true value of a quantity can never be known. This means that, in practice, the error in an individual measurement can never be quantified. Instead, we can quantify the expected statistical distribution of the errors. This is typically done by the **standard uncertainty** (also called simply **uncertainty**), which is the standard deviation of the statistical distribution of the errors that are likely to affect the measurement result [3].

Experimental measurements should be reported as follows:

$$x = \bar{x} \pm u(\bar{x}) \tag{1}$$

where $\bar{x}$ is the best estimate of the measured quantity, either the measurement result or the average of several measurement results if available, and $u(\bar{x})$ is the (standard) measurement uncertainty.

In case of **systematic errors** arising from the instrument, the statistical distribution is usually not provided by the manufacturer, who provides only the maximum error (i.e. the accuracy), sometimes separated into different contributions (e.g., offset, gain, nonlinearity, resolution, etc.). When no other information is available, we can assume that the statistical distribution of the error is uniform in the range $\pm a$, where a is the accuracy (or the maximum value of any type of systematic error). Therefore the uncertainty is calculated as the standard deviation of a uniform probability distribution:

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$$u = \frac{a}{\sqrt{3}} \tag{2}$$

In case of **random errors**, if n repeated measurements are available, the uncertainty can be estimated by the standard deviation of the population of measurements x_i, divided by $\sqrt{n}$:

$$u(\bar{x}) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n(n-1)}} \tag{3}$$

where

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4}$$

Example-1: Three voltages were measured to be 6.25 V, 6.31 V and 6.20 V. The mean voltage = (6.25 + 6.31 + 6.20)/3 = 6.2533 V, the standard uncertainty can be found to be 0.0319 V. Hence, the voltage can be expressed as (6.25 ± 0.03) V.

2.5 Significant figures

The significant figures in an experimental measurement are important to reflect precision. They include all the numbers that can be read directly from the instrument scale plus one more estimated number (if applicable). Writing the number in scientific or powers-of-10 notation shows explicitly all the significant figures in your measurement. This procedure is helpful in expressing the significant figures in very large (and very small) numbers. The uncertainty typically has 1 significant figure, and there is no point behind using more significant figures (i.e. higher precision) than the uncertainty itself.

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Example-2: If the uncertainty in measuring a certain current is 0.1 mA, and the value of the current is 6.482 mA, then it would be wrong to report the current as I=6.482 ± 0.1 mA. Rather, it should be reported as I=6.5 ± 0.1 mA.

In the multiplication or division of two or more measurements, the number of significant figures in the final answer equals the number of the **least** significant figures in the measurements, while for addition and subtraction, the number of significant figures in the final answer depends on the number of decimals in the measurements. No more decimal places than the **fewest** decimal places should be retained.

Example-3: $V = IR = (12.34 \text{ A}) \times (5600 \ \Omega) = (1.234 \times 10^1 \text{ A}) \times (5.6 \times 10^3 \ \Omega)$.

Hence: $V = 69104$ V $= 6.9 \times 10^4$ V (2 significant figures).

Example-4: $V = V_1 + V_2 = 12.34$ V + 5.6789 V = 18.0189 V = 18.02 V (2 decimal places).

2.6 Reducing errors

It is desirable to reduce as far as possible the uncertainty associated with any value. Several methods to reduce errors can be followed depending on the type of error.

Reducing systematic errors

- Using equipment with best possible accuracy (i.e., smallest errors).
- Making full use of available scale (e.g. analogue meters/gauges, oscilloscope voltage and time scale) ?
- For small values not much larger than the instrument resolution, measure the sum of known number of items. For example, one could measure the thickness of a sheet of paper, or measure the thickness of 100 sheets then divide by 100.

Reducing random errors

- Following appropriate experimental techniques.
- Careful connections, grounding, reducing of nodes and connectors.
- Consistency in measurement technique.
- Take repeated measurements, then calculate the best estimate of the expected value by using the mean; the uncertainty will be reduced by a factor $\sqrt{n}$, as shown in equation 3.

2.7 Presenting results

As explained above, measurement results should always be reported in the form:

$$x = \bar{x} \pm u(\bar{x}) \tag{5}$$

Although the error with respect to the "true value" cannot be evaluated, it is possible to define and quantify an "error" with respect to the expected value of a quantity when this is known.

If the best measured value is x=$\bar{x}$ $\pm$ $u(\bar{x})$ and you were expecting (i.e. theoretically) a value of x_{exp} then the discrepancy or error between the measured and the expected results can be indicated as an **absolute error**:

$$Error_{abs} = |x_{exp} - \bar{x}| \tag{6}$$

The error can also be expressed as percentage of the expected value:

$$Error_{\%} = \frac{Error_{abs}}{|x_{exp}|} \times 100\% \tag{7}$$

If this absolute error is less than $u(\bar{x})$ (the uncertainty in the measurement), then the two values are sufficiently close to be in agreement. If the expected value itself has a margin of error or uncertainty δx, then there should be some finite overlap between the expected range $x_{exp} \pm \delta x$ and the measured range x=$\bar{x}$ $\pm$ $u(\bar{x})$ for the measurement to be considered accurate enough to be accepted.

For example, the expected resistance value of a resistor is the nominal value provided by the manufacturer, but that value has a **tolerance**, also provided by the manufacturer, which is the maximum error of the actual resistance with respect to the nominal value. The expected value is therefore affected by this error, which should be taken into account when comparing the expected value with a measurement result.

3 Introduction to SK10 Boards - Build and Test Experiment

The construction and testing of prototype circuits for testing designs is a vital skill for any electrical engineer. It is also important to present results and analysis in a clear, professional format. This laboratory session and the report you submit will develop these skills.

3.1 Apparatus

- DC power supply (make a note of the make and model),
- Function generator (make a note of the make and model),
- Oscilloscope (make a note of the make and model),
- Digital multimeter (make a note of the make and model),
- SK10 bread board,
- Transistors BC109, resistances and capacitances (different values).

3.2 The SK10 board

The SK10 board (schematic in the Appendix B) is designed for prototyping electronic circuits. Electrical conductors are arranged in parallel. Electronic components can be inserted into the board to make contact with the conductors. The central break in the SK10 is designed to allow integrated circuits of the dual in-line (DIL) type to be directly inserted. Connections between components are made using short lengths of wire.

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Good practice when using SK10 boards:

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- Use the parallel tracks on the outside of the board for your power supply lines.
- Twist the wires connecting your power supply to your circuit together to minimise electrical pickup.
- Always use a colour scheme for your wiring (and stick to it).
- Always use the shortest possible length of wire to connect between components (don't make big loops).

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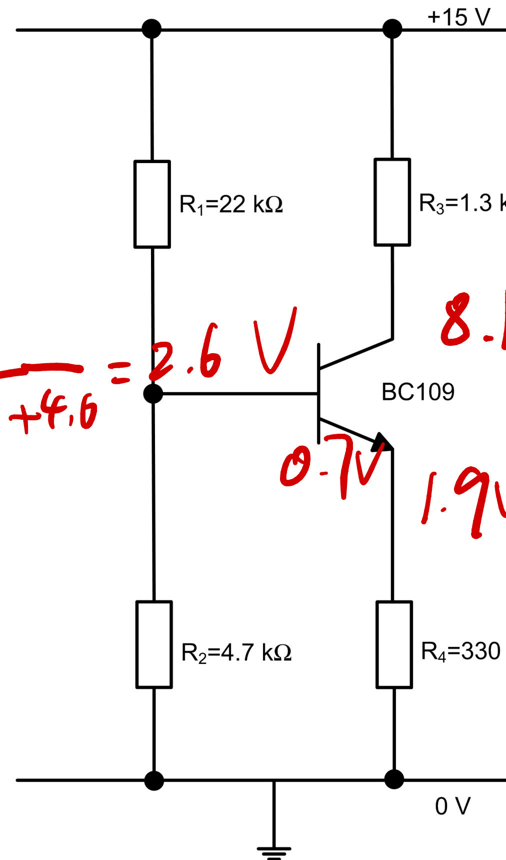
- Always wire around integrated circuits, don't take a wire over the top (otherwise you will have to remove the wire to take out the device).
- Always build up the circuit one section at a time. Test that this part works before continuing.

If you are having problems, check the common problems information at Appendix A.

4 The Practical work: Part I - DC bias of a Common Emitter amplifier (20 Marks)

In this experiment, you will build a basic transistor amplifier known as a common emitter amplifier using transistor BC109 (Data sheet is available in Appendix E) as shown in the circuit of Figure 2).

Follow the steps below to build the circuit and refer to the "Good practice when using SK10 boards" in the section above.



$15 \times \frac{4.6}{21.9+4.6} = 2.6\ V$

8.1 V

0.7V

1.9V

$V = IR$

Figure 2: Circuit for part I

$V_c = 15 - \frac{I_E}{1+\frac{1}{\beta}} R_3 = 15 - \frac{\frac{1.9}{323}}{1+\frac{1}{520}}$ 1.17k

4.1 Step 0: Oscilloscope calibration

- Calibrate channel 1 and channel 2 of your oscilloscope. Ensure that the test waveform appears as expected. N.B. If you are not familiar with oscilloscope calibration, please refer back to "Exp Q-The Oscilloscope" from your Y1 study. The lab script for this experiment is available on VITAL (Learning Resources→Supporting Material folder).

If you have problems ask a demonstrator and continue with step 1 while you wait.

4.2 Step 1: Power supply connections

- Take two long wires (one red and one black), strip the ends and twist the wires together (don't twist the bare ends together).
- Connect one end of the red wire to the positive terminal of your power supply and one end of the black wire to the negative supply.

- Connect the other end of each wire to one of the parallel sets of lines along the edge of the SK10 (Put the red wire onto the top line and the black wire onto the bottom line).
- Now, using the oscilloscope with proper scope probes set the power supply voltage to 15 V and check that this voltage is seen along the positive supply rail on your SK10. Make a note of the resolution of this measurement.

4.3 Step 2: Base bias

- Using the resistor colour codes, make a note of the percentage and absolute tolerances of all the resistors used in this experiment. Put these values in a table.
- Connect the two resistors R_1 and R_2 on Figure 2. The top lead of R_1 should be attached to the positive supply rail with the bottom lead pushed into one of the central conductors of the SK10. Note: make sure that when using any resistance to measure and record its value.
- One lead of R_2 should be inserted into the same central conductor as R_1 with the other lead attached to the negative (or common) supply rail.

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- Test that the voltage on the central conductor (where R_1 and R_2 join) is equal to about 2.5 V. Make a note of the exact value and include this in your report. Make sure you make a note also of the resolution of this measurement.

4.4 Step 3: Inserting the transistor

- Take a BC109 transistor and identify the three leads from the data sheet (found near the technician's room). This process is prone to error so if you are not sure, ask.
- Insert the transistor into the SK10 with the three leads in separate conductors.
- Make a connection from the join of R_1 and R_2 to the base of the transistor.
- Add R_4 such that one lead connects to the emitter of the transistor and the other lead connects to the negative (common) supply line.
- Add R_3 such that one lead connects to the collector of the transistor and the other lead connects to the positive supply line.

4.5 Step 4: Testing the circuit

- Using the oscilloscope measure the DC voltage on the base, on the collector and on the emitter of the transistor.
- Copy the table below into your logbook and fill in the expected and measured values, and calculate the absolute and relative (%) errors.

	Expected (V)	Measured (V)	Uncertainty	Abs. error	% error
Base voltage		2.80/2.60			
Emitter voltage		2.00			
Collector voltage		8.20			

second

2.80/2.60

2.00

8.40

4.6 Step 5: Effect of changing the transistor

- Remove the transistor from your circuit, select another BC109 and insert this instead (take care to connect it correctly).
- Measure the Base, Emitter and Collector voltages again. Comment on any differences seen. Include the same table above in your report.

5 The Practical work: Part II - Amplification of AC signals (20 Marks)

In order to obtain larger gains when amplifying AC signals, we must include some additional components.

Capacitors block DC currents but allow higher frequency signals to pass. For the amplifier of Figure 3, capacitor C_1 blocks DC offsets from any input circuit, C_2 prevents the DC offset of the transistor from affecting later output parts of a circuit and C_3 bypasses R_4, allowing larger gains.

5.1 Step 1: Adding capacitors

- Add capacitors to your circuit so it has the configuration shown in Figure 3.

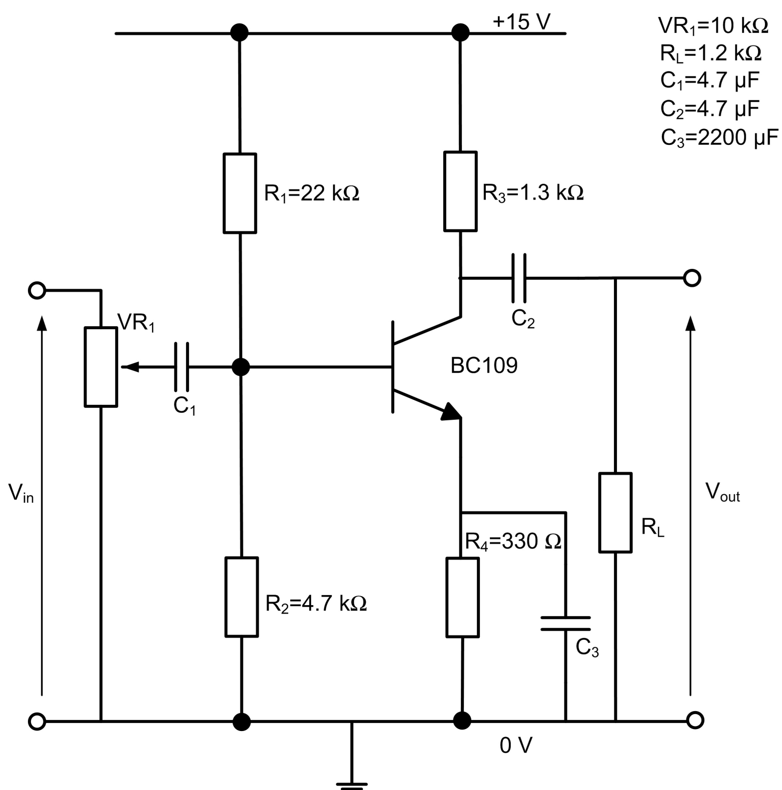

Figure 3: Circuit for part II

5.2 Step 2: Adding a load

- Add a load resistor R_L, as shown on Figure 3 (make sure it is connected to the negative (common) line).

5.3 Step 3: Testing the circuit

- Connect the output from a signal generator to the top of variable resistor VR_1. Connect the bottom lead of VR_1 to the negative line with the slider output connected to the input of your circuit.
- Connect the common line from the signal generator to the common line of your circuit.
- Set the frequency of the signal generated by the signal generator to 1000 Hz and the amplitude of the signal (measure at capacitor C_1) to 50 mV peak-to-peak. Adjust the amplitude using the amplitude control on the signal generator and by adjusting the variable resistor. Test the input and output signals using your oscilloscope, and take a note of the resolution of the voltage and frequency measurements.

input
Vpp 50.4mV~51.2mV
f 994.0~1.005k

- Measure the voltage across the load resistor R_L, using the oscilloscope. Hence, calculate the gain of the amplifier.

Output
Vpp 4.48V
f 998.0~1.000Hz

Vpp 9.68V

- Increase the amplitude of the input signal until the output signal becomes distorted. Find the maximum amplitude of input signal that the circuit can handle. Record your findings.
- Reduce the input amplitude back down to 50 mV peak-to-peak.
- Change the transistor for another BC109. Document any difference due to this to the amplitude of the signal on the collector.

input
Vpp 51.2~52.8mV
f 997.0~1.010Hz

output
Vpp 4.48V
f 1.000kHz

distortion Vpp 9.52V

6 Error Analysis (30 Marks)

- **Measurement uncertainties**
  1. List each type of measurement carried out accompanied by the types of uncertainty associated with each.
  2. Give numerical values to all these uncertainties. Refer to the instrument specifications to determine its accuracy (or maximum error); report all measurements in the form $x \pm u(x)$.
  3. Referring to the table of voltages in section 4.5, comment on whether the results are in agreement with expectation, taking the uncertainty into account and comparing this with the absolute error.

- **Error sources**
  1. What factor or constraint had the greatest effect on the uncertainty of your results?
  2. Discuss any other factors or constraints which had an impact on your data.
  3. How could the error have been reduced?

- **Bonus question**

  When taking repeated measurements to reduce the random error by a factor $\sqrt{n}$ comment on any assumption made concerning the underlying statistical distribution of the measurements. Can you suggest a way to estimate (approximate) the standard uncertainty without having to calculate Equation 3? Be sure to cite any references used.

7 Discussions and Conclusions (20 Marks)

- Summarise the experiment and formulate conclusions for your report.
- Answer the following questions:
  - What effect does changing the transistor have on the DC bias and hence the AC gain?
  - Is there any affect of the input frequency (AC situation) on the response of the amplifier? Explain your answer.
  - Which part of the experiment was most successful? Why?
  - What changes could be made to improve the experiment?

8 Report Writing and Marking Scheme

This experiment is assessed by means of a formal report. Reports that get 70% and above are first-class reports only. Please refer to Appendix F to read about report marking descriptors.

The marking scheme for the report of this experiment is as follows:

- Results of Part I with explanation and comments: **20 Marks**
- Results of Part II with explanation and comments: **20 Marks**
- Error Analysis section: **30 Marks**
- Discussions and Conclusions section: **20 Marks**
- Overall report presentation: **10 Marks**

N.B. The overall report mark will be scaled to 90% and combined with the 10% of the pre-lab test to generate the final mark of this experiment.

9 Plagiarism and Collusion

Plagiarism and collusion or fabrication of data is always treated seriously, and action appropriate to the circumstances is always taken. The procedure followed by the University in all cases where plagiarism, collusion or fabrication is suspected is detailed in the University's Policy for Dealing with Plagiarism, Collusion and Fabrication of Data, Code of Practice on Assessment, Category C, available on `https://www.liverpool.ac.uk/media/livacuk/tqsd/code-of-practice-on-assessment/appendix_L_cop_assess.pdf`.

Follow the following guidelines to avoid any problems:

(1) Do your work yourself.

(2) Acknowledge all your sources.

(3) Present your results as they are.

(4) Restrict access to your work.

References

[1] J. Taylor, "An Introduction to Error Analysis: The Study of Uncertainties if Physical Measurements", University Science Books, 1982.

[2] P. Bork, H. Grote, D. Notz and M. Regler, "Data Analysis Techniques in High Energy Physics Experiments", Cambridge University Press, 1993.

[3] JCGM 100:2008, "Guide to the Expression of Uncertainty in Measurement", 2008.

Version history

Name	**Date**	**Version**
Dr M López-Benítez	September 2019	Ver. 4.1
Dr R Ferrero	September 2018	Ver. 4.0
Dr A Al-Ataby	August 2015	Ver. 3.3
Dr A Al-Ataby	August 2014	Ver. 3.2
Dr A Al-Ataby	September 2013	Ver. 3.1
Dr A Al-Ataby and Dr W Al-Nuaimy	October 2012	Ver. 3.0
Mr G Bunting	Febuary 2009	Ver. 2.1
Mr G Bunting	October 2007	Ver. 2.0
Dr J S Marsland	August 2000	Ver. 1.0

Appendix A - Common problems

SK10 boards

- Components shorted out due to incorrect connections:

  Make sure that you do not have two of the terminals from one device connected together by inserting the component into a single track of the SK10.

- Components not connected or powered:

  You must link your components using wire. Ensure that your components are connected to the appropriate power supplies.

- Tracks shorted out:

  When you strip the ends off the wires, only take off a small length of insulator. Do not push too much bare wire down into the SK10 as this can move under the conductors and cause a short circuit.

- Internal breaks in the SK10 board:

  See Figure 4 in Appendix B. Ensure that any required links are made. If you encounter problems test that your devices are getting the expected voltages.

- Failure to connect Ground potential:

  All electronic circuits require that current can flow from the positive terminal of your power supply to the negative terminal. Check that your circuit has connections to both terminals.

- Incorrect usage of bipolar power supply:

  Many applications require both positive and negative power supply rails. Use a dual power supply and couple the positive terminal of one supply to the negative terminal of the other. This joined connection now acts as the common (ground) connection.

Other possible problems

- Check that the oscilloscope is set up correctly, use the calibration point to check.
- If a value of a resistor is not available, think about preferred values, resistor tolerances...etc (see Appendix D).
- Check that all the resistors you use are the correct value, use a multi-meter. (It is possible that resistors get mixed up in the storage boxes.)
- Check that your transistor is working, use the transistor curve tracer.

Appendix B - SK10 Bread Board

The breadboard you will obtain from the technician is a series of holes electrically connected underneath. Figure 4 below gives an idea of what lies beneath the surface of the breadboard.

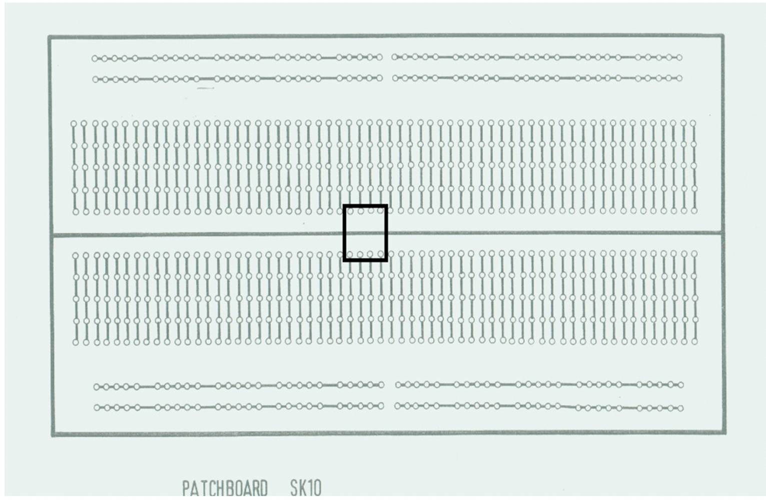

Figure 4: SK10 Bread Board

Appendix C - Resistor Colour Code

The resistor colour code is a way of showing the value of a resistor. Instead of writing the resistance on its body, which would often be too small to read, a colour code is used. Ten different colours represent the numbers 0 to 9. The first two coloured bands on the body are the first two digits of the resistance, and the third band is the 'multiplier'. Multiplier just means the number of zeros to add after the first two digits. Red represents the number 2, so a resistor with red, red, red bands has a resistance of 2 followed by 2 followed by 2 zeros, which is 2 200 ohms or 2.2 kilohms. Sometimes written as 2K2 .
The final band is the tolerance (the accuracy). All the standard laboratory resistors are 5% which is shown by a gold band.

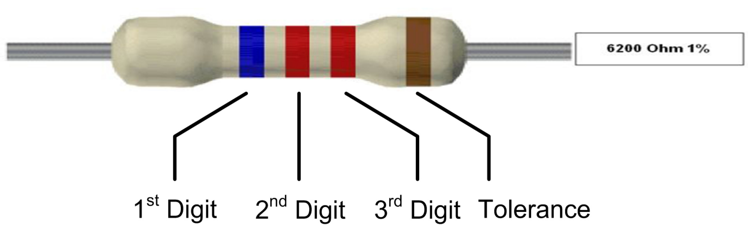

Figure 5: Resistance colour code

Here are some examples:
Yellow, purple, red, gold = 47 x 100 = 4 700 ohms = 4.7 kilohms
Brown, black, yellow, gold = 10 x 10 000 = 100 kilohms
Yellow, purple, black, gold = 47 x 1 = 47 ohms
Brown, black, red, gold = 10 x 100 = 1 000 ohms = 1 kilohms
Brown, black, green, gold = 10 x 100 000 = 1 000 kilohms = 1 Megohms
All +/- 5%

Color	Band 1, 1^{st} Figure	Band 2, 2^{nd} Figure	Band 3, 3^{rd} Figure	Band 4, Tolerance
Black	0	0	10^0	
Brown	1	1	10^1	1%
Red	2	2	10^2	2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	5%
Silver			10^{-2}	10%
None				20%

Appendix D - Preferred Resistor Values

Resistors are available in a number of standard ranges, often called 'preferred values' These ranges, or series, are set out by the Electronic Industries Association (EIA), and are E6, E12, E24, E48, E96 and E192. The number after the 'E' denotes the number of values the series contains per decade. The most common series is probably E24. The series are logarithmic and are derived from the resistor tolerance; resistors with a tighter tolerance can have more values in the series that won't overlap one another. The series are sometimes referred to by the tolerance, the two being related as follows:

E6: 20% tolerance (None)
E12: 10% tolerance (Silver)
E24: 5% tolerance (Gold)
E48: 2% tolerance (Red)
E96: 1% tolerance (Brown)
E192: less than 1% tolerance

When designing a circuit you need to round calculated resistor values to a preferred value. Normally this would be the value closest to the calculated one for the series you are using. However, in some circumstances, it's better to round up to the next higher value, such as with current limiting resistors where using a value smaller than calculated could overload a component. The tables below show the values for some of the more common preferred series.

E12 Series:

1R0	10R	100R	1K0	10K	100K	1M0	10M
1R2	12R	120R	1K2	12K	120K	1M2	
1R5	15R	150R	1K5	15K	150K	1M5	
1R8	18R	180R	1K8	18K	180K	1M8	
2R2	22R	220R	2K2	22K	220K	2M2	
2R7	27R	270R	2K7	27K	270K	2M7	
3R3	33R	330R	3K3	33K	330K	3M3	
3R9	39R	390R	3K9	39K	390K	3M9	
4R7	47R	470R	4K7	47K	470K	4M7	
5R6	56R	560R	5K6	56K	560K	5M6	
6R8	68R	680R	6K8	68K	680K	6M8	
8R2	82R	820R	8K2	82K	820K	8M2	

E24 Series:

1R0	10R	100R	1K0	10K	100K	1M0	10M
1R1	11R	110R	1K1	11K	110K	1M1	
1R2	12R	120R	1K2	12K	120K	1M2	
1R3	13R	130R	1K3	13K	130K	1M3	
1R5	15R	150R	1K5	15K	150K	1M5	
1R6	16R	160R	1K6	16K	160K	1M6	
1R8	18R	180R	1K8	18K	180K	1M8	
2R0	20R	200R	2K0	20K	200K	2M0	
2R2	22R	220R	2K2	22K	220K	2M2	
2R4	24R	240R	2K4	24K	240K	2M4	
2R7	27R	270R	2K7	27K	270K	2M7	
3R0	30R	300R	3K0	30K	300K	3M0	
3R3	33R	330R	3K3	33K	330K	3M3	
3R6	36R	360R	3K6	36K	360K	3M6	
3R9	39R	390R	3K9	39K	390K	3M9	
4R3	43R	430R	4K3	43K	430K	4M3	
4R7	47R	470R	4K7	47K	470K	4M7	
5R1	51R	510R	5K1	51K	510K	5M1	
5R6	56R	560R	5K6	56K	560K	5M6	
6R2	62R	620R	6K2	62K	620K	6M2	
6R8	68R	680R	6K8	68K	680K	6M8	
7R5	75R	750R	7K5	75K	750K	7M5	
8R2	82R	820R	8K2	82K	820K	8M2	
9R1	91R	910R	9K1	91K	910K	9M1	

E48 Series:
The values of the decade 100-1000 for the E48 series are:

100, 105, 110, 115, 121, 127, 133, 140, 147, 154, 162, 169, 178, 187, 196, 205, 215, 226, 237, 249, 261, 274, 287, 301, 316, 332, 348, 365, 383, 402, 422, 442, 464, 487, 511, 536, 562, 590, 619, 649, 681, 715, 750, 787, 825, 866, 909, 953

Multiply or divide the values by 10 for other decades.

E96 Series:
The values of the decade 100-1000 for the E96 series are:

100, 102, 105, 107, 110, 113, 115, 118, 121, 124, 127, 130, 133, 137, 140, 143, 147, 150, 154, 158, 162, 165, 169, 174, 178, 182, 187, 191, 196, 200, 205, 210, 215, 221, 226, 232, 237, 243, 249, 255, 261, 267, 274, 280, 287, 294, 301, 309, 316, 324, 332, 340, 348, 357, 365, 374, 383, 392, 402, 412, 422, 432, 442, 453, 464, 475, 487, 491, 511, 523, 536, 549, 562, 576, 590, 604, 619, 634, 649, 665, 681, 698, 715, 732, 750, 768, 787, 806, 825, 845, 866, 887, 909, 931, 959, 976

Multiply or divide the values by 10 for other decades.

E192 Series:
The values of the decade 100-1000 for the E192 series are:

100, 101, 102, 104, 105, 106, 107, 109, 110, 111, 113, 114, 115, 117, 118, 120, 121, 123, 124, 126, 127, 129, 130, 132, 133, 135, 137, 138, 140, 142, 143, 145, 147, 149, 150, 152, 154, 156, 158, 160, 162, 164, 165, 167, 169, 172, 174, 176, 178, 180, 182, 184, 187, 189, 191, 193, 196, 198, 200, 203, 205, 208, 210, 213, 215, 218, 221, 223, 226, 229, 232, 234, 237, 240, 243, 246, 249, 252, 255, 258, 261, 264, 267, 271, 274, 277, 280, 284, 287, 291, 294, 298, 301, 305, 309, 312, 316, 320, 324, 328, 332, 336, 340, 344, 348, 352, 357, 361, 365, 370, 374, 379, 383, 388, 392, 397, 402, 407, 412, 417, 422, 427, 432, 437, 442, 448, 453, 459, 464, 470, 475, 481, 487, 493, 499, 505, 511, 517, 523, 530, 536, 542, 549, 556, 562, 569, 576, 583, 590, 597, 604, 612, 619, 626, 634, 642, 649, 657, 665, 673, 681, 690, 698, 706, 715, 723, 732, 741, 750, 759, 768, 777, 787, 796, 806, 816, 825, 835, 845, 856, 866, 876, 887, 898, 909, 920, 931, 942, 953, 965, 976, 988

Multiply or divide the values by 10 for other decades.

FEATURES

- Low current (max. 100 mA)
- Low voltage (max. 45 V).

APPLICATIONS

- General purpose switching and amplification.

DESCRIPTION

NPN transistor in a TO-18; SOT18 metal package.
PNP complement: BC177.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to the case

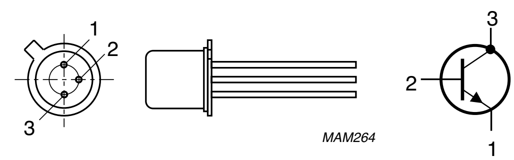

Fig.1 Simplified outline (TO-18; SOT18) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	BC107		–	50	V
	BC108; BC109		–	30	V
V_{CEO}	collector-emitter voltage	open base			
	BC107		–	45	V
	BC108; BC109		–	20	V
I_{CM}	peak collector current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	300	mW
h_{FE}	DC current gain	$I_C = 2$ mA; $V_{CE} = 5$ V			
	BC107		110	450	
	BC108		110	800	
	BC109		200	800	
f_T	transition frequency	$I_C = 10$ mA; $V_{CE} = 5$ V; f = 100 MHz	100	–	MHz

CHARACTERISTICS

T_j = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{CBO}	collector cut-off current	I_E = 0; V_{CB} = 20 V	–	–	15	nA
		I_E = 0; V_{CB} = 20 V; T_j = 150 °C	–	–	15	μA
I_{EBO}	emitter cut-off current	I_C = 0; V_{EB} = 5 V	–	–	50	nA
h_{FE}	DC current gain	I_C = 10 μA; V_{CE} = 5 V				
	BC107A; BC108A		–	90	–	
	BC107B; BC108B; BC109B		40	150	–	
	BC108C; BC109C		100	270	–	
h_{FE}	DC current gain	I_C = 2 mA; V_{CE} = 5 V				
	BC107A; BC108A		110	180	220	
	BC107B; BC108B; BC109B		200	290	450	
	BC108C; BC109C		420	520	800	
V_{CEsat}	collector-emitter saturation voltage	I_C = 10 mA; I_B = 0.5 mA	–	90	250	mV
		I_C = 100 mA; I_B = 5 mA	–	200	600	mV
V_{BEsat}	base-emitter saturation voltage	I_C = 10 mA; I_B = 0.5 mA; note 1	–	700	–	mV
		I_C = 100 mA; I_B = 5 mA; note 1	–	900	–	mV
V_{BE}	base-emitter voltage	I_C = 2 mA; V_{CE} = 5 V; note 2	550	620	700	mV
		I_C = 10 mA; V_{CE} = 5 V; note 2	–	–	770	mV
C_c	collector capacitance	$I_E = i_e$ = 0; V_{CB} = 10 V; f = 1 MHz	–	2.5	6	pF
C_e	emitter capacitance	$I_C = i_c$ = 0; V_{EB} = 0.5 V; f = 1 MHz	–	9	–	pF
f_T	transition frequency	I_C = 10 mA; V_{CB} = 5 V; f = 100 MHz	100	–	–	MHz
F	noise figure	I_C = 200 μA; V_{CE} = 5 V; R_S = 2 kΩ; f = 30 Hz to 15.7 kHz				
	BC109B; BC109C		–	–	4	dB
F	noise figure	I_C = 200 μA; V_{CE} = 5 V; R_S = 2 kΩ; f = 1 kHz; B = 200 Hz				
	BC107A; BC108A BC107B; BC108B; BC108C		–	–	10	dB
	BC109B; BC109C		–	–	4	dB

Notes

1. V_{BEsat} decreases by about 1.7 mV/K with increasing temperature.
2. V_{BE} decreases by about 2 mV/K with increasing temperature.

Appendix E – Report Marking Descriptors

Mark Range	Knowledge and Understanding	Intellectual and Practical Skills	Transferable Skills
90-99% ‘Outstanding’	Total coverage of the task set. Exceptional demonstration of knowledge and understanding appropriately grounded in theory and relevant literature.	Extremely creative and imaginative approach. Comprehensive and accurate analysis. Well-argued conclusions. Perceptive self-assessment.	Extremely clear exposition. Excellently structured and logical response. Excellent presentation, only the most insignificant errors, suitable for use as “model report”.
80-89% ‘Excellent’	As ‘Outstanding’ but with some minor weaknesses or gaps in knowledge and understanding.	As ‘Outstanding’ but slightly less imaginative and with some minor gaps in analysis and/or conclusions.	As ‘Outstanding’ but with some minor weaknesses in structure, logic and/or presentation. Quality of reporting is very high.
70-79% ‘Very Good’	Full coverage of the task set. Generally very good demonstration of knowledge and understanding but with some modest gaps. Good grounding in theory.	Some creative and imaginative features. Very good and generally accurate analysis. Sound conclusions. Some self-assessment. Demonstrates an understanding of the broader context of the task.	Generally clear exposition. Satisfactory structure. Very good presentation, largely free of grammatical and other errors. Reporting is professional and well-presented.
60-69% ‘Comprehensive’	As ‘Very Good’ but with more and/or more significant gaps in knowledge and understanding and some significant gaps in grounding	As ‘Very Good’ but analysis and conclusions contain some minor weaknesses, oversights and/or inaccuracies.	As ‘Very Good’ but with some weaknesses in exposition and/or structure and a few more grammatical and other errors.
50-59% ‘Competent’	Covers most of the task set. Patchy knowledge and understanding with limited grounding in literature.	Rather limited creative and imaginative features. Patchy analysis containing significant flaws. Rather limited conclusions. No self-assessment.	Competent exposition and structure. Competent presentation but some significant presentational and structural errors. For example, figures may be poorly labelled and data tabulation may be poor.
40-49% ‘Adequate’	As ‘Competent’ but patchy coverage of the task set and more weaknesses and/or omissions in knowledge and understanding. Just meets the threshold level.	As ‘Competent’ but probably without much imagination. Shows barely adequate ability to analyse and draw conclusions. Just meets the threshold level.	As ‘Competent’ but with more weaknesses in exposition, structure, presentation and/or errors. Just meets the threshold level.
35-39% ‘Compensatable fail’	Some parts of the set task likely to have been omitted. Major gaps in knowledge and understanding. Some significant confusion. Very limited grounding. Falls just short of the threshold level.	No creative or imaginative features. Analysis and conclusions rather limited. Falls just short of the threshold level.	Somewhat confused and limited exposition. Confused structure. Some weaknesses in presentation and some serious presentational and mathematical errors. Falls just short of the threshold level.
20-34% ‘Deficient’	As ‘Compensatable Fail’ but with major omissions and/or major gaps in knowledge and understanding, and/or incorrect approach towards the experimental task Falls substantially below the threshold level.	As ‘Compensatable Fail’ but analysis and/or conclusions may have been omitted, and practical work is substantially below the threshold level. Demonstrates inability to operate or manipulate equipment.	As ‘Compensatable Fail’ but with more serious weaknesses in delivery of presentation. Falls substantially below the threshold level.
0-20% ‘Extremely weak’	Substantial sections of the task not covered. Knowledge and understanding of the task and the laboratory environment very limited and/or largely incorrect. No grounding in theory.	No creative or imaginative features. No report as suc, just collection of notes and/or plots. Analysis extremely weak or omitted. No conclusions.	Largely confused exposition and structure. Many serious errors in presentation of data

Feedback:

If you have any feedback on your laboratory experience for this experiment (e.g. timing, difficulty, clarity of script, demonstration ...etc) and suggestions to how the experiment may be improved in the future, please write them down in the space below. This feedback is important for future versions of this script and to enhance the laboratory process, and will not be assessed. If you wish to provide this feedback anonymously, you may do so by detaching this page and submitting it to the Student Support Centre (fifth floor office).

Script re-writing award
If you think that this experiment could do with enhancement or changes and you have some ideas that you'd like to share, why not re-write this script yourself and you may get an award from lab organisers with an official letter of thanks, and your name will be added to the version history list in future versions of the script. Something good for your CV.
Contact one of the lab organisers for more details.