Lab-Volt® Basic Electricity & Electronics

Transistor Amplifier Circuits

FACET®

Student Workbook

FOURTH EDITION

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Table of Contents

Introduction

This Student Workbook provides a unit-by-unit outline of the Fault Assisted Circuits for Electronics Training (F.A.C.E.T.) curriculum.

The following information is included together with space to take notes as you move through the curriculum.

- The unit objective
- Unit fundamentals
- A list of new terms and words for the unit
- Equipment required for the unit
- The exercise objectives
- Exercise discussion
- Exercise notes

The **Appendix** includes safety information.
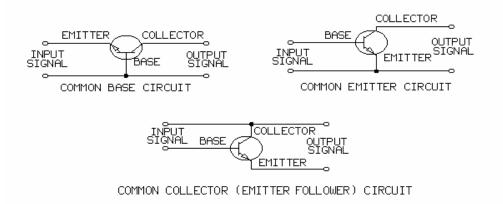
UNIT 1 – INTRODUCTION TO TRANSISTOR AMPLIFIERS

UNIT OBJECTIVE

At the completion of this unit, you will be able to identify, connect, and operate circuit blocks and their major components on the TRANSISTOR AMPLIFIER CIRCUITS circuit board.

UNIT FUNDAMENTALS

This unit describes the circuit blocks on the TRANSISTOR AMPLIFIER CIRCUITS circuit board and presents some background on transistor amplifiers.

Transistor amplifiers are grouped into one of three basic circuit configurations depending on which transistor element is common to input and output signal circuits.

1. Common base
2. Common emitter
3. Common collector

Each circuit configuration has its own characteristics and, therefore, its own applications.

Multistage transistor amplifiers include more than one transistor. The output of the first stage is connected (coupled) to the input of the second stage. The output of the second stage is coupled to the input of the third stage, and so forth.

The three methods of coupling amplifier stages on the TRANSISTOR AMPLIFIER CIRCUITS circuit board are RC coupling, transformer coupling, and direct coupling.

1

NEW TERMS AND WORDS

Multistage - an amplifier circuit that uses more than one active component (transistor).
active component - a circuit component that controls gain or directs current flow.
gain - the amount by which an amplifier increases signal voltage, current, or power; expressed as a ratio of the output to input value.
distortion - undesired change to a signal waveform.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Circuit Location and Identification

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to locate and identify the functional circuit blocks on the TRANSISTOR AMPLIFIER CIRCUITS circuit board. You will observe the operation of two basic amplifier circuits by using an oscilloscope.

DISCUSSION

- Amplifiers are circuits that increase the voltage, current, or power of an input signal.
- An amplifier consists of an active circuit component and a source of power.
- Transistors are the active components used on this circuit board. The power source is the external power supply.
- Five amplifier circuit blocks, which can be configured for seven different circuits, are present on the TRANSISTOR AMPLIFIER CIRCUITS circuit board.
- The five amplifier circuit blocks are the:
  - COMMON BASE / EMITTER circuit block
  - RC COUPLING/TRANSFORMER COUPLING circuit block
  - COMMON COLLECTOR circuit block
  - BIAS STABILIZATION circuit block
  - DIRECT COUPLING circuit block
- Potentiometer R4 is the load resistor on the COMMON COLLECTOR circuit block.
- The BIAS STABILIZATION circuit block does not use a sine wave generator, instead, it uses a positive, variable, dc power supply. In addition, this circuit block has a resistor, labeled HEATER which is located near the transistor, that is powered by a separate dc power supply.
- The RC COUPLING/TRANSFORMER COUPLING and the DIRECT COUPLING circuit blocks include components that are used to demonstrate two-stage amplification.
- All transistors on the TRANSISTOR AMPLIFIER CIRCUITS circuit board are NPN except for the second stage PNP transistor on the DIRECT COUPLING circuit block.

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Exercise 2 – Multistage Amplifier Introduction

EXERCISE OBJECTIVE

When you have completed this exercise, you will have observed the operation of a two-stage transistor amplifier circuit. You will view your results on an oscilloscope.

DISCUSSION
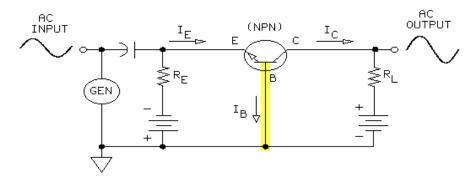
- Multistage transistor amplifiers utilize multiple transistors to produce voltage, current, or power gains greater than those provided by a single transistor.
- Multistage transistor amplifiers are identified by the method used to couple the signal between amplifier stages.
- Resistor-capacitor (RC) coupling uses a resistor to develop an output signal and a capacitor to pass the signal from the output of one stage to another.
- Transformer coupling uses a transformer to couple signals between the primary and the secondary side of the coil.
- In multistage amplifiers, capacitors are used to isolate the dc bias levels and simplify the design.
- All amplifiers are designed for a specific frequency range and an input/output signal amplitude range.
- An input signal that is too large or outside the frequency range of an amplifier will produce a distorted output signal.

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UNIT 2 – COMMON BASE CIRCUIT
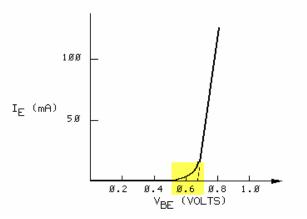
UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of the common base transistor amplifier circuit by using calculated and measured circuit conditions.
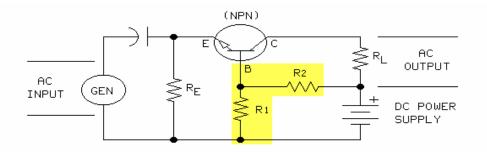
UNIT FUNDAMENTALS

The base terminal is common to the input and output signals in the common base (CB) transistor circuit. The ac output signal of a common base (CB) circuit is in phase with the input signal. For a PNP or NPN transistor to function normally in any type of amplifier circuit, the base-emitter junction is forward biased, and the base-collector junction is reversed biased.

The emitter current (I_E) increases very rapidly after the transistor is forward biased [base-emitter voltage (V_{BE}) of about 0.6 Vdc].

Proper biasing of a CB transistor circuit can be provided by a connection between the base terminal and a voltage divider circuit across a single dc power supply.

NEW TERMS AND WORDS

active region - the region on the transistor load line between the saturation point and the cutoff point.
Q-point (quiescent point) - the dc steady state operating point set by the dc bias conditions.
cutoff point - the point on the load line where the collector current is essentially zero.
saturation point - the point on the load line where the collector current is maximum.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Common Base Circuit DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of a common base (CB) transistor circuit by using a typical CB circuit. You will verify your results with a multimeter.

DISCUSSION

- In common base amplifier circuits the base terminal is common to both the input and output signals.
- The voltage divider network provides the fixed dc base voltage required to forward bias the base-emitter junction of the transistor.
- The voltage divider equation can be used to calculate the base voltage (V_B).
- V_{BE}, base-emitter voltage, of a forward biased silicon transistor is approximately 0.6 V.
- The emitter voltage (V_E) is the difference between the base voltage and the base-emitter voltage. $V_E = V_B - V_{BE}$
- Ohm's law is used to calculate both emitter current (I_E) and collector current (I_C).
- Collector current can be found in two other ways: First the collector current is approximately equal to the emitter current. Second the collector current is the difference between the emitter current and the base current. $I_C = I_E - I_B$
- Transistor characteristic curves and dc load lines are used to determine the Q (quiescent) point, dc-point, or operating point of the transistor circuit.
- Saturation occurs when the base-collector voltage is zero.

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Exercise 2 – Common Base Circuit AC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine ac operating characteristics of a common base (CB) amplifier by using a typical CB circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The sine wave generator provides the ac input signal.
- Ac signals at the base are shorted to ground by capacitor C2.
- The ac output signal is between capacitor C3 (located at the collector of Q1) and ground.
- The input impedance of the common base configuration is very low while the output impedance is very high.
- Low input impedance causes loading of the input signal.
- The high ratio of output to input impedance creates a circuit with high gains.
- Common base transistor circuits are used in applications which require high output gains.
- The ac output signal is in phase with the input signal.
- Voltage gain of the common base circuit is the ratio of the output voltage to the input voltage, or the ratio of the load and input impedance.

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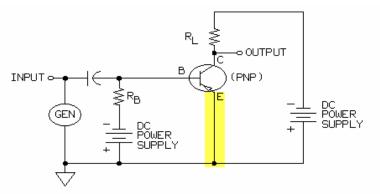
UNIT 3 – COMMON EMITTER CIRCUIT
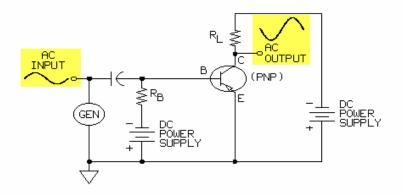
UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a common emitter transistor amplifier circuit by using calculated and measured circuit conditions.
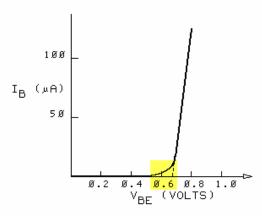
UNIT FUNDAMENTALS
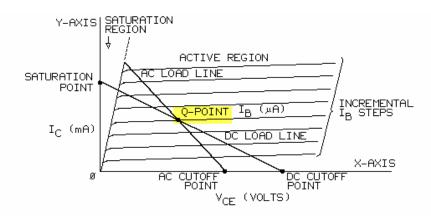
The emitter terminal is common to the input and output signals of the common emitter (CE) transistor circuit.
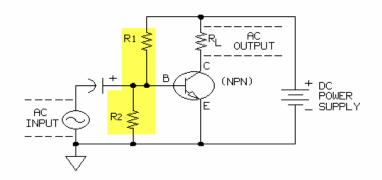
The ac output signal of a CE circuit is 180° out of phase with the ac input signal.

After a base-emitter voltage (V_{BE}) of about 0.6 Vdc, the base current (I_B) increases very rapidly.

The transistor circuit ac and dc load lines intersect at the Q-point on the collector current characteristic curves.

A voltage divider circuit uses a single dc power supply to provide a constant base terminal voltage for the CE transistor. The CE circuit has high current, voltage, and power gains. The input and output impedances are high.

NEW TERMS AND WORDS

beta - the symbol used for the ratio of the dc collector current to the dc base current.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Common Emitter Circuit DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of a common emitter (CE) transistor circuit by using a typical CE circuit. You will verify your results with a multimeter and calculations.

DISCUSSION

- The emitter terminal is common to both the input and output signals.
- Base voltage (V_B) can be calculated from the voltage divider equation.
- Ohm's law is used to calculate the emitter current (I_E).
- The emitter current and collector current (I_C) are nearly equal. The exact collector current can be found by subtracting the base current from the emitter current.
- Current gain is the ratio of dc collector current to base current. Dc current gain is represented by beta (β_{dc}) or h_{FE} and usually ranges in value between 10 and 500.
- Design criteria for a common emitter circuit specifies a collector voltage (V_C) about halfway between the power supply voltage (V_A) and the emitter voltage (V_E).
- The saturation point occurs when the collector-emitter voltage (V_{CE}) is zero and collector current is maximum ($I_{C(SAT)}$).
- Cuffoff occurs when collector current is approximately zero.
- The area on a transistor characteristic curve between saturation and cutoff is called the active region.
- The Q-point of a transistor is determined by its dc bias conditions. Q-point is the where the dc load line intersects the base current, collector current, and the collector-emitter voltage curves.
- The ideal location of the Q-point is at the midpoint of the dc load line.

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Exercise 2 – Common Emitter Circuit AC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the ac operating characteristics of a common emitter (CE) amplifier by using a typical CE transistor circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The ac input signal is provided by the sine wave generator. The ac output signal is taken between the collector terminal and ground. The parallel resistance of R4 and R6 is the load.
- The ac output voltage is larger and 180° out of phase with the input signal.
- As base voltage increases, base current increases, this results in an increase in the collector and emitter currents.
- The voltage gain of a common emitter circuit is the ratio of the ac output voltage to the ac input voltage. $Av = -Vo/Vi$ (where the negative sign indicates that there is a 180° phase shift.)
- The gain of a CE circuit where an emitter resistor is not bypassed by a capacitor is equal to the ratio of the collector load (R_L) to the emitter resistor (R5). $Av = -R_L/R5$
- Connecting the Q-point with the $I_{C(SAT)}$ point and drawing a line to the X-axis provides the value of the ac cutoff voltage and the ac load line.
- Large ac input signals, which are so large that the peak output voltage exceeds the maximum allowed by the cutoff point, cause clipping at the output.
- The optimum Q-point is at the center of the ac load line.

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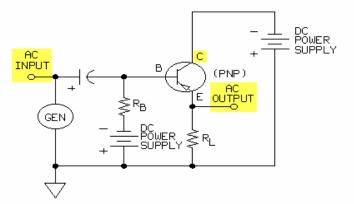
UNIT 4 – COMMON COLLECTOR CIRCUIT
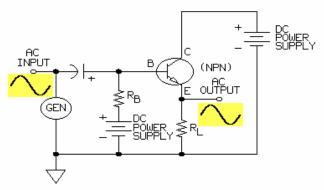
UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a common collector transistor amplifier circuit by using calculated and measured circuit conditions.
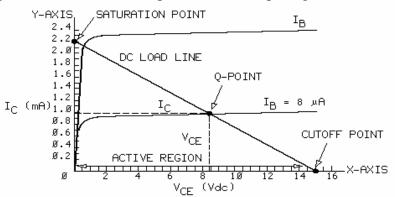
UNIT FUNDAMENTALS
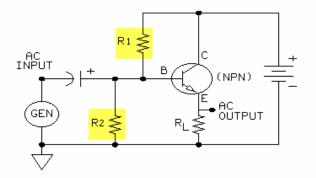
The collector terminal is common to the input and output signals of the common collector (CC) transistor circuit.

The ac output signal of a CC circuit is in phase with the input signal.

The CC transistor circuit base and collector current characteristic curves are similar to the CE circuit curves.

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A CC transistor voltage divider circuit biases the base terminal with a single dc power supply. The CC circuit has a voltage gain less than 1.0 and has current gains between 10 and 500.

High input impedance and low output impedance make the CC transistor circuit desirable for applications between a high impedance source and a low impedance load.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Common Collector Circuit DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of a common collector (CC) transistor circuit by using a typical CC circuit. You will verify your results with a multimeter and with calculations.

DISCUSSION

- In common collector transistor circuits the collector terminal is common to both the input and the output signals.
- Since no collector resistor is present the collector voltage (V_C) equals the dc power supply voltage (V_A).
- Base voltage (V_B) is calculated using the voltage divider equation.
- Emitter voltage (V_E) is about 0.6 Vdc less than the base voltage when the transistor is operating normally.
- Ohm's law is used to calculate the emitter current (I_E).
- Collector current (I_C) is the emitter current minus the base current.
- The dc load line passes through the saturation point, Q-point, and the cutoff point.
- Cutoff occurs when V_{CE} is equal to the supply voltage and I_C equals 0 mA.
- Saturation occurs when V_{CE} equals 0 Vdc and the I_C is at maximum value.

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Exercise 2 – Common Collector Circuit AC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine ac operating characteristics of a common collector (CC) amplifier by using a typical CC transistor circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION
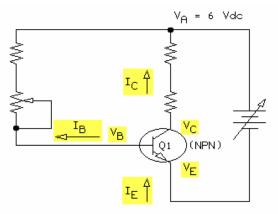
- The ac input is provided by a sine wave generator.
- The ac output is taken between the emitter terminal and ground.
- Voltage gain of the common collector transistor circuit is the ratio of the ac output voltage to the ac input voltage. The voltage gain is always less than one.
- The input and output signal are in phase.
- The common collector transistor circuit is also called an emitter follower because the output signal follows the input signal.
- Input impedance (Zi) is equal to the combined parallel resistance of R1, R2, and β x (R3 + re'). Since β x (R3 + re') is more than 100 times as large as R1 in parallel with R2, this parallel combination equals the input impedance.
- This circuit block allows the student to measure output impedance (Zo) by connecting potentiometer R4 in parallel with R3 and adjusting R4 until the output signal is half that of the original.

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UNIT 5 – BIAS STABILIZATION

UNIT OBJECTIVE
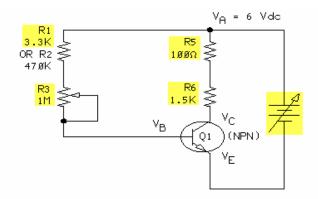
At the completion of this unit, you will be able to demonstrate the effect of a temperature increase on transistor bias by using typical transistor amplifier bias circuits.

UNIT FUNDAMENTALS
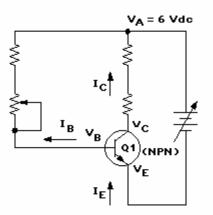
Transistor bias refers to the dc operating conditions: the base, collector, and emitter dc voltages and currents.
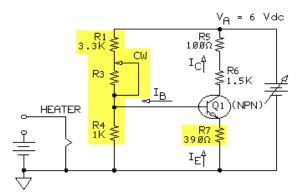
Transistor bias depends on the dc voltage supply and on the values and configuration of the circuit resistors.

The Q-point of the load line is determined by the transistor bias. Transistors are heat-sensitive devices. A change in transistor temperature can adversely affect the output signal quality.

If a circuit is not designed to overcome the effects of temperature change, the location of the Q-point can move toward the saturation or cut-off points causing signal distortion.

A transistor amplifier circuit with a base voltage divider and an emitter resistor fixes the bias voltage levels and, therefore, has good bias temperature stability. The stability factor (S) is a measure of a transistor circuit's bias stability with changes in temperature.

NEW TERMS AND WORDS

collector leakage current (ICBO) - current caused by the reverse bias voltage between the collector and the base. ICBO increases with temperature.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Clock
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Temperature Effect on Fixed Bias

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to describe the effect of temperature on a fixed bias circuit by using a typical transistor circuit. You will verify your results with a multimeter, a clock, and calculations.

DISCUSSION

- Increased transistor temperature creates an increase in the value of beta (β, current gain) and the collector leakage current (I_{CBO}).
- Collector leakage current (I_{CBO}) is caused by the reverse bias voltage. I_{CBO} is measured from the base to the collector with the emitter open.
- Collector leakage current is normally in the nanoampere range, but doubles with every 10° C increase.
- In a fixed bias circuit, changes in beta have the greatest effect on the collector current.
- Large temperature increases can cause collector current to reach the saturation point or create a thermal runaway condition that could damage the transistor.
- A measure of transistor temperature stability is referred to as the stability factor (S). The stability factor is a ratio of the change in collector current to the change in collector leakage current.
- Stability factors can range in value from one to as high as beta. A low stability factor indicates a temperature stable transistor. Values less than 10 are considered good.
- Fixed bias, or simple bias, circuits have poor temperature stability. The stability factor is equal to beta.
- In a fixed bias circuit, increased temperature causes V_{BE} to decrease resulting in an increase of both the voltage drop across R3 and the base current.
- Base current increase cause an increase in collector current. Increases in beta and collector leakage current compound the collector current increase.
- Fixed bias circuits are usually used for transistor circuits that provide a switching function. The circuit operates at saturation and cutoff.

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Exercise 2 – Temperature Effect on Voltage Divider

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to describe the temperature effects on a voltage divider bias circuit by using a typical transistor circuit. You will verify your results with a multimeter, a clock, and calculations.

DISCUSSION

- The collector current is almost independent of beta in a voltage divider bias circuit. Therefore when beta changes with temperature, it has little effect on circuit bias.
- When the resistors in the voltage divider network are selected correctly, the base voltage is essentially constant. Constant base voltage and the feedback from the emitter resistor give the voltage divider bias circuit good temperature stability.
- Increasing temperatures cause an increase in the collector and emitter currents. Larger emitter currents increase the emitter voltage which opposes and slightly increases base voltage. A slight increase in base voltage creates a decrease in base current thus counteracting the collector and emitter current increase.
- Feedback is the effect on the base voltage caused by the increase in emitter voltage.
- The larger the emitter resistance the better the temperature stability of the circuit.
- Too large an emitter resistor will limit the voltage gain of the circuit and bring the Q-point closer to the saturation point, limiting the ac signal operating range.
- The stability factor (S) of the voltage divider bias circuit is approximately equal to the ratio of R4 to R7. A stability factor of ten or less is desirable.

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UNIT 6 – TRANSISTOR SPECIFICATION SHEET

UNIT OBJECTIVE

At the completion of this unit, you will be able to cite transistor parameters by using a transistor specification sheet.

UNIT FUNDAMENTALS

A transistor parameter is a physical or an electrical property whose value determines the characteristics or behavior of the transistor. The transistor specification (data) sheet summarizes all the transistor parameters and technical data that the manufacturer considers important for the user. The user should refer to the specification sheet when selecting a transistor for a specific circuit application.

A typical transistor specification sheet contains:
1. A listing of the manufacturer's transistor identification numbers and transistor casing types.
2. Maximum ratings.
3. Electrical characteristics.
4. Characteristic curves.
5. Mechanical features.

Some important transistor parameters include:
1. Current gain (h_{FE}).
2. Maximum power dissipation (P_D).
3. Saturation voltages ($V_{CE(sat)}$ and $V_{BE(sat)}$ are measures of conductivity).
4. Collector leakage (cutoff) current (I_{CBO}).
5. Breakdown voltage ($V_{(BR)CEO}$, $V_{(BR)CBO}$, $V_{(BR)EBO}$).
6. Switching characteristics.
7. Noise (NF).

Transistor specification sheets are contained in the manufacturer's technical information book. Such books usually cover the family of devices to which a transistor belongs.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Transistor Parameters Familiarization

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with several transistor parameter symbols. You will verify your knowledge with a list of common transistor parameter symbols and meanings.

DISCUSSION

- Several frequently used transistor parameter symbols and their meanings are presented to the students.
- The symbols are composed of letters which appear in the name or definition of the parameter.
- Capital letter subscripts are sometimes used to denote dc or maximum values.
- Lower case subscript letters usually represent ac (dynamic, rms, or instantaneous) values.
- Terminal junctions are indicated by subscripts in the abbreviation of the parameter.

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Exercise 2 – Using the Transistor Specification Sheet

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to locate maximum ratings, dc characteristics, and operating parameters by using a typical transistor specification sheet. You will verify your results by successfully completing all tasks.

DISCUSSION

- Manufacturer's of transistors publish technical manuals which include the transistor specification (data) sheets.
- The manual usually contains an alphanumeric index indicating the page number where data on a specific transistor is located.
- Manuals, also, include information to help select the correct transistor for the application and tables that compare specific transistor performance for general design or applications groupings.
- Specification sheets include sections for maximum ratings, electrical characteristics, and characteristic curves.
- Included in the data sheet are the transistor identification numbers, casing types, applications, transistor configuration, and material.
- Maximum ratings section provides operating parameters when a transistor is at its maximum rating.
- The Electrical Characteristics section consists of the following categories that provide maximum and minimum parameter values required for circuit design.

  > Off characteristics
  > On characteristics
  > Small-signal characteristics
  > Switching Characteristics
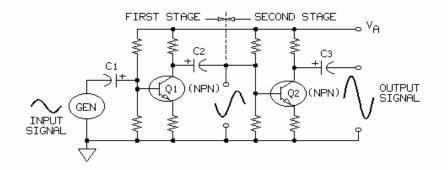
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UNIT 7 – RC COUPLING

UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a two-stage RC-coupled amplifier by using measured circuit conditions.

UNIT FUNDAMENTALS

Two amplifiers are **cascaded** when the output of the first amplifier is connected to the input of the second amplifier. In a cascaded system, the first amplifier is called the first stage. The second amplifier is called the second stage. Cascaded amplifiers achieve an overall gain higher than that possible with one amplifier.

When a capacitor and one or more resistors connect the output of the first stage to the input of the second stage, the amplifiers are RC (resistance-capacitance) coupled. With common-emitter circuits, each amplifier inverts the input signal so that the output of the second stage is in phase with the input of the first stage. The manner in which gain varies with the frequency of the input signal is called **frequency response**.

NEW TERMS AND WORDS

cascaded - when the output of the first stage is connected to the input of the second stage.
frequency response - the manner in which gain varies with the frequency of the input signal.
bandwidth - the range of signal frequencies over which the gain is relatively constant.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of an RC-coupled amplifier by using measured values. You will verify your results with a multimeter.

DISCUSSION

- This RC coupling circuit consists of two cascaded common emitter NPN amplifiers (Q1 and Q2).
- The output of the first transistor is connected to the input (base) of the second transistor through the coupling capacitor C2.
- The coupling capacitor blocks the dc collector current of Q1 from entering the base of Q2. The coupling capacitor prevents dc interaction and shifting of both transistor Q-points.
- RC stands for resistance-capacitance.
- Both transistors have the identical voltage divider circuit and the same component values; therefore, the dc bias for each transistor is essentially the same.

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Exercise 2 – AC Voltage Gain and Phase

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the ac voltage gain and the input/output phase relationship of an RC-coupled amplifier by using measured and calculated values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The sine wave input is applied to the base of the first amplifier.
- The output of the first amplifier depends on the ac output load resistance of Q1. Since C2 passes ac signals, the ac load resistance (R_{L1}) consists of the parallel combination R3, R4, R8, and the Q2 β x (R10 + r'_e).
- Q2 β x (R10 + r'_e) is large and may be eliminated from the calculation.
- The first amplifier has a voltage gain (A_{v1}) which is the ratio of the output to input signal (V_{o1}/V_{i1}). The gain has a negative sign since this stage inverts.
- The ratio of load resistance to the emitter resistance approximates the voltage gain of the first amplifier.

$$A_{v1} = -R_{L1}/R_5$$

- The ac output load resistance of Q2 is equal to the value of the collector resistor (R9).
- Voltage gain of the second amplifier is expressed using this equation:

$$A_{v2} = -V_{o2}/V_{i2} = -R_{L2}/R_{10} = -R_9/R_{10}$$

- Overall circuit gain is the product of the amplifier gain.

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Exercise 3 – Frequency Response

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the frequency response of an RC-coupled amplifier by using measured values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION
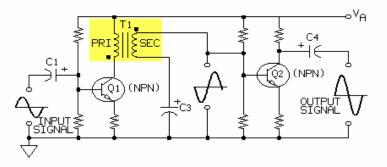
- Amplifier gain varies as the input signal frequency varies. This behavior is referred to as the frequency response.
- The amplifier circuit used in this exercise experiences decreases in gain at frequencies below 20 Hz and above 100 kHz.
- The bandwidth of an amplifier is the range of input signal frequencies over which the amplifier gain remains constant.
- In general, a 15% decrease in amplifier gain indicates that the amplifier is at the end of its bandwidth range.
- Frequency response curves for audio amplifiers should be relatively flat between 20 Hz and 20 kHz.
- The coupling capacitor value may affect frequency response (at the lower frequencies) of the amplifier.
- Upper limit frequency bandwidth is affected by the frequency-dependent transistor parameters and the stray capacitance of circuit elements.

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UNIT 8 – TRANSFORMER COUPLING
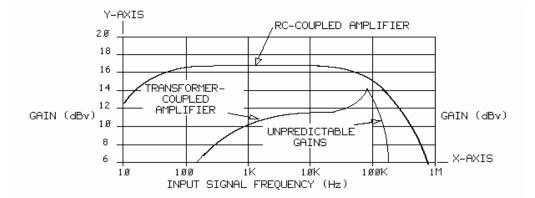
UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a transformer-coupled two-stage amplifier by using measured circuit conditions.

UNIT FUNDAMENTALS

When a transformer connects the output of the first-stage amplifier to the input of the second-stage amplifier, the amplifiers are transformer-coupled. The transformer matches the high output impedance of the first-stage amplifier (Q1) with the low input impedance of the second-stage amplifier (Q2). A transformer-coupled amplifier uses less power than an RC-coupled amplifier does because the dc voltage drop across a transformer winding is less than that of a collector resistor, permitting a smaller dc supply voltage.

The frequency response of a transformer-coupled amplifier is normally poorer than that of an RC-coupled amplifier.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of a transformer-coupled two-stage amplifier by using measured values. You will verify your results with a multimeter.

DISCUSSION

- The transformer-coupled amplifier circuit consists of two NPN common emitter amplifiers (Q1 and Q2).
- The transformer T1 has its primary winding connected between the power supply and the collector terminal of the first stage amplifier.
- The secondary winding of the transformer is connected to the base terminal of the second-stage amplifier and to ground through a dc current-blocking capacitor (C3).
- Transformer (T1) blocks dc current flow between the two amplifier stages. This isolates the dc bias for each stage.
- Transformers are circuit devices used for ac signals only.
- Resistor R7, which is connected in parallel with the transformer secondary winding, maintains the impedance specification of this coil.
- The amplifiers have identical voltage divider circuits and emitter resistors causing V_B and V_E of each transistor to have about the same value.
- The resistance of the primary winding is small; therefore, the collector voltage of the first stage (V_{C1}) is slightly less than the dc supply voltage (V_A).
- The second stage of the amplifier has a collector resistor (R9) which produces a collector voltage (V_{C2}) of about 9 Vdc.

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Exercise 2 – AC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the ac voltage gain, impedance matching, and input/output phase relationship of a transformer-coupled amplifier by using measured and calculated values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The ac input signal to the base of the first amplifier stage is provided by the sine wave generator.
- Transformer T1 has its primary connected between the power supply and the collector of the first stage amplifier.
- The secondary is connected to the base of the second-stage amplifier and to ground through a dc blocking capacitor (C3).
- The transformer provides impedance matching between the low impedance of the second-stage base circuit and the high impedance of the first stage collector output.
- The primary winding impedance (Z_P) is represented as: $Z_P = Z_S \times (N_P/N_S)^2$
    where Z_S is the impedance of the secondary
        N_P/N_S is the turns ratio of the transformer
- The impedance of the second-stage base circuit is equal to the parallel combination of R7, R8, and $\beta \times (r_e + R10)$.
- The turns ration of this transformer is 1.96.
- The ac peak-to-peak voltage between the primary and secondary coils is reduced (stepped down) by the transformer. The reduction is proportional to the turns ratio.
- The dot on the bottom of the primary and the dot on the top of the secondary indicate that the signals at these points are in phase.
- The voltage gain of the first-stage is equal to the ratio of the output voltage to the input voltage. $A_{v1} = -V_{o1}/V_{i1}$ Note: The negative sign indicates a phase inversion.
- The ac output signals of each amplifier are measured from their respective bases.
- The first stage output signal is smaller than the first stage collector signal because the transformer steps down the signal.
- The collector resistor R9 is the ac output load of Q2.
- The voltage gain of the amplifier's second stage can be expressed by any of the following equations: $A_{v2} = -V_{o2}/V_{i2}$
                $A_{v2} = -R_{L2}/R10$
                $A_{v2} = -R9/R10$
- The overall amplifier gain is the product of the gains of the individual amplifier stages.
- The output signal of stage 2 is not quite in phase with the input signal of stage 1. This is caused by the inductive reactance of the transformer.
- The ac cutoff of V_{ce} is higher than the dc supply voltage because of the transformer action.

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Exercise 3 – Frequency Response

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the frequency response of a transformer-coupled amplifier by using measured values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- Voltage gain can be expressed using a logarithmic scale, the unit of logarithmic voltage gain is decibels (dB).
- This equation is used to convert voltage gain into its logarithmic equivalent:

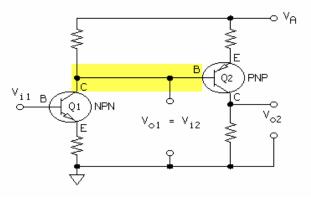$$A_{vdB} = 20 \log_{10} (V_o/V_i) = 20 \log_{10} (A_v)$$

- Decibels are used because human hearing has a logarithmic response.
- Doubling the decibel level is the equivalent to a tenfold increase in arithmetic gain.
- Voltage gain in dBs is plotted against the frequency of the input signal, the resulting curve is referred to as the frequency response.
- Transformer-coupled amplifiers have a poorer frequency response than RC-coupled amplifiers. This occurs because the transformer frequency response is limited in comparison to an RC coupling circuit.
- The transformer used on the TRANSISTOR AMPLIFIER CIRCUITS circuit board has a frequency response spec of ±2 dB between 200 Hz and 10 KHz.

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UNIT 9 – DIRECT COUPLING

UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a direct-coupled, two-stage amplifier by using measured circuit conditions.

UNIT FUNDAMENTALS

When the output of the first-stage amplifier (Q1) is directly connected to the input of the second-stage amplifier (Q2), the amplifiers are direct coupled.

The frequency response at low frequencies is very good for direct-coupled amplifiers. The dc conditions of each amplifier stage are not isolated. A direct-coupled amplifier is temperature sensitive and requires stabilizing circuits to minimize drifting of the dc bias.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
Multimeter
Oscilloscope, dual trace
Generator, sine wave
TRANSISTOR AMPLIFIER CIRCUITS circuit board

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Exercise 1 – Direct-Coupled Amplifier DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the dc operating conditions of a direct-coupled, two-stage amplifier by using measured values. You will verify your results with a multimeter.

DISCUSSION

- The direct-coupled two-stage amplifier circuit consists of two transistors configured as common emitters. The first stage, Q1, uses an NPN transistor and the second stage, Q2, uses a PNP transistor.
- The output of Q1 (the collector) connects directly into the input of Q2 (the base). The collector voltage of Q1 is equal to the base voltage of Q2. ($V_{C1} = V_{B2}$)
- The emitter voltage (V_{E2}) is about 0.6 Vdc more positive than the base voltage (V_{B2}) when the base-emitter junction of Q2 is forward biased.
- The collector voltage (V_{C2}) is less positive than the base voltage (V_{B2}) since the base-collector junction is normally reverse biased.
- The first stage has a voltage divider network to set the dc bias. The collector voltage of this stage sets the base voltage of the second stage.
- The second stage does not use a voltage divider to establish the dc bias; the resulting bias is more sensitive to temperature changes.
- The emitter resistor in the second stage generates feedback that counteracts dc bias drift due to temperature. But, it is not as effective as voltage divider bias.

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Exercise 2 – Direct-Coupled Amplifier AC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the ac voltage gain and the input/output phase relationship of a direct-coupled amplifier by using measured and calculated values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The sine wave generator provides the input signal. The signal enters the base of the first-stage amplifier.
- Input and output signal are in phase because each common emitter inverts the signal.
- The voltage gain of Q1 is found with these equations:
$$A_{v1} = -V_{o1}/V_{i1} = -R4/R5$$
- The voltage gain of Q2 is expressed by any of these equations:
$$A_{v2} = -V_{o2}/V_{i2} = -R_{L2}/R6 = -R7/R6$$
- The overall circuit voltage gain is the product of the two amplifier gains.

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Exercise 3 – Direct-Coupled Amp Frequency Response

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the frequency response of a direct-coupled amplifier by using measured values. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The bandwidth of a direct-coupled amplifier can extend to frequencies below 5 Hz.
- Direct-coupled amplifier frequency response is good at low frequencies because of the lack of a capacitor in the connection path.
- Amplifier gain is reduced at low frequencies because of capacitive reactance.
- The high frequency bandwidth limit is limited by frequency-dependent amplifier parameters and stray circuit capacitance.
- RC-coupled amplifiers have a capacitive reactance large enough to reduce gain at frequencies below 50 Hz.
- Transformer-coupled amplifiers have reduced gain at lower frequencies because of the transformer characteristics.

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APPENDIX A – SAFETY

Safety is everyone's responsibility. All must cooperate to create the safest possible working environment. Students must be reminded of the potential for harm, given common sense safety rules, and instructed to follow the electrical safety rules.

Any environment can be hazardous when it is unfamiliar. TheFACET. computer-based laboratory may be a new environment to some students. Instruct students in the proper use of theFACET. equipment and explain what behavior is expected of them in this laboratory. It is up to the instructor to provide the necessary introduction to the learning environment and the equipment. This task will prevent injury to both student and equipment.

The voltage and current used in theFACET. Computer-Based Laboratory are, in themselves, harmless to the normal, healthy person. However, an electrical shock coming as a surprise will be uncomfortable and may cause a reaction that could create injury. The students should be made aware of the following electrical safety rules.

1. Turn off the power before working on a circuit.
2. Always confirm that the circuit is wired correctly before turning on the power. If required, have your instructor check your circuit wiring.
3. Perform the experiments as you are instructed: do not deviate from the documentation.
4. Never touch "live" wires with your bare hands or with tools.
5. Always hold test leads by their insulated areas.
6. Be aware that some components can become very hot during operation. (However, this is not a normal condition for yourFACET. course equipment.) Always allow time for the components to cool before proceeding to touch or remove them from the circuit.
7. Do not work without supervision. Be sure someone is nearby to shut off the power and provide first aid in case of an accident.
8. Remove power cords by the plug, not by pulling on the cord. Check for cracked or broken insulation on the cord.