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Transistor Power Amplifiers

FACET®

Student Workbook

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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 – CIRCUIT BOARD FAMILIARIZATION

UNIT OBJECTIVE

At the completion of this unit, you will be able to identify the circuit blocks and their major components on the TRANSISTOR POWER AMPLIFIERS circuit board. You will connect some circuits and observe their operation.

UNIT FUNDAMENTALS

Radio and television receivers, public address systems, tape recorders, and other electronic devices use transistor power amplifiers.

This unit describes the circuit blocks on the TRANSISTOR POWER AMPLIFIER circuit board. Other units include exercises that will help you understand the principles of each type of power amplifier on the circuit board.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

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

NOTES

Exercise 1 – Circuit Location and Identification

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the circuit blocks on the TRANSISTOR POWER AMPLIFIERS circuit board. You will verify your results by identifying circuit components and connecting two power amplifier circuits.

DISCUSSION

- Several types of transistor power amplifier circuits can be demonstrated with the TRANSISTOR POWER AMPLIFIERS circuit board.
- Fixed (15.0 Vdc) and variable positive dc positive supplies are used in the transistor amplifier circuits.
- Use the ATTENUATOR when small ac input signals are required.
- The DARLINGTON PAIR circuit block does not use a signal generator.
- The PHASE SPLITTER circuit block has two output signals.
- Transformers are used in input and output circuits of some power amplifiers.

NOTES

Exercise 2 – Transistor Power Amplifier Introduction

EXERCISE OBJECTIVE

When you have completed this exercise, you will have observed the operation of two power amplifier circuits. You will view your results on an oscilloscope.

DISCUSSION

- Transistor power amplifiers increase the signal power.
- The amplitude of the output signal voltage is usually less than the input voltage.
- The output current is appreciably greater than the input current.

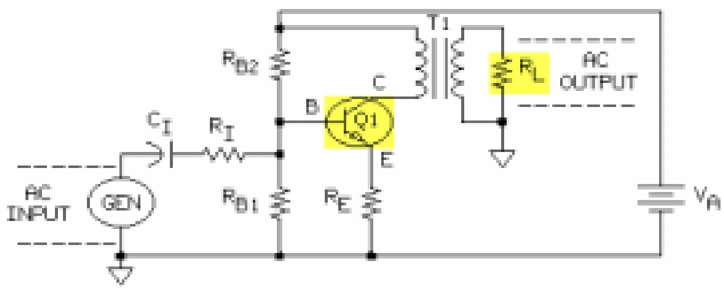
NOTES

UNIT 2 – SINGLE-ENDED POWER AMPLIFIER

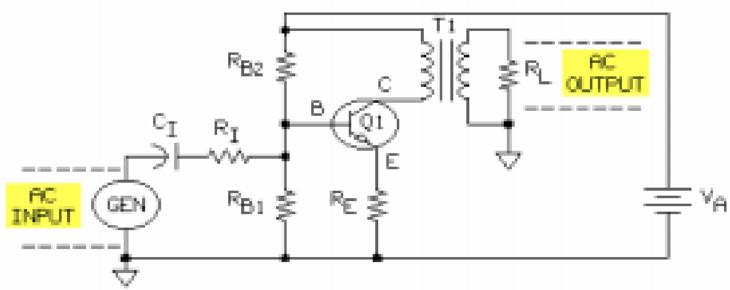
UNIT OBJECTIVE

At the completion of this unit, you will be able to describe the operation of a single-ended power amplifier by using ac and dc measurements.

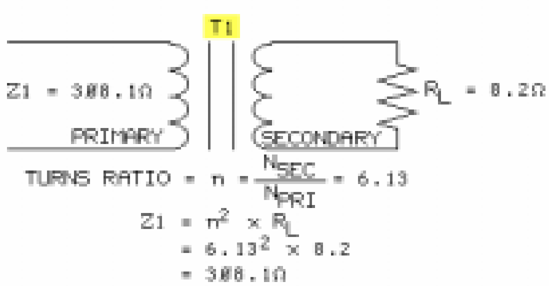
UNIT FUNDAMENTALS



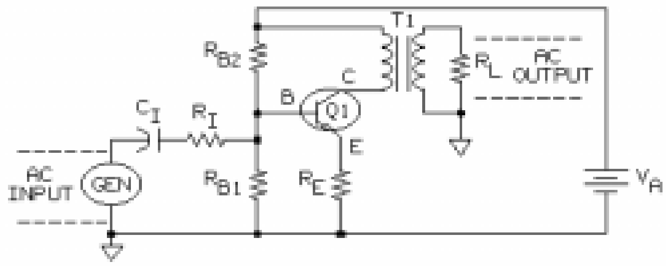
A single-ended **power amplifier** circuit is shown. It has a single transistor (Q1) controlling a current through a load (R_L).



The ac signal is input at RI to the base of Q1; the output signal is across R_L in the secondary coil of the transformer (T1).



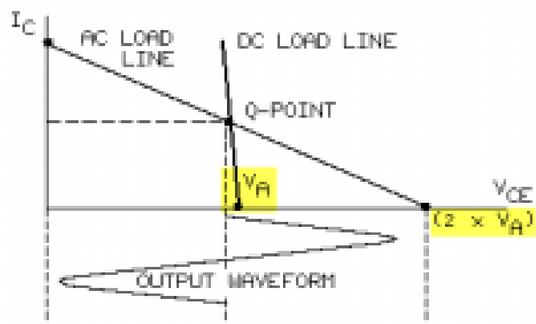
The transformer (T1) is used as an impedance matching device. T1 matches the relatively high impedance (Z1 = 308.1Ω) of the Q1 collector circuit in the T1 primary coil with a low impedance load (R_L = 8.2Ω) in the T1 secondary coil.



Power gain (A_p) is determined by the ratio of the output power (P_o) to the input power (P_i) or the product of voltage gain (Av) and current gain (Ai).

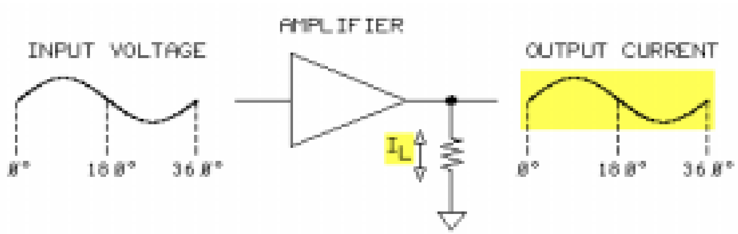
$$A_p = P_o/P_i = Av \times Ai$$

Power amplifiers have high power gain but low voltage gain.



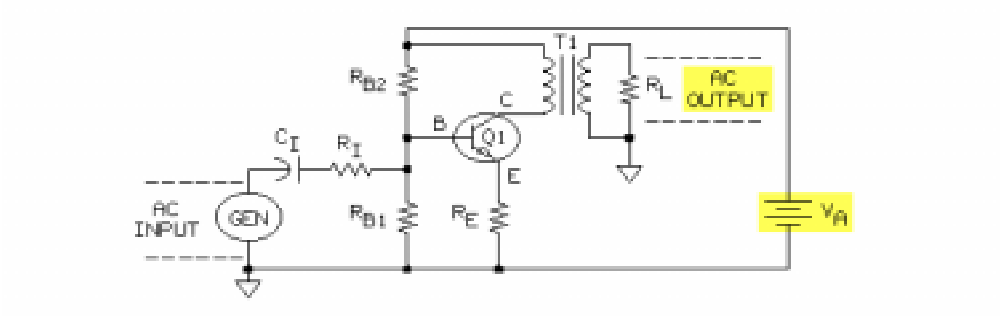
The peak of the collector-emitter voltage (V_{CE}) may exceed the dc supply voltage (V_A) by a factor of two, as shown in the figure.

When a single-ended power amplifier is designed, V_{CE} must not exceed the transistor specification.



Amplifiers can be classified as class A, B, or C. The single-ended power amplifier is biased for continuous current flow (I_L), which causes class A operation.

Because output current flows continuously, class A is the least efficient class of amplifier, but it produces an output signal with practically no amplitude distortion.



A power amplifier's efficiency is determined by the ac output power of the load (R_L) divided by the dc power of the supply (V_A).

NEW TERMS AND WORDS

power amplifier - amplifier that increases the signal power from the input to the output.

EQUIPMENT REQUIRED

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

NOTES

Exercise 1 – DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to measure dc operating voltages and currents by using a typical single-ended power amplifier circuit. You will verify your results with a multimeter.

DISCUSSION

- Transistor Q1 is an NPN transistor connected in a common emitter configuration.
- The collector voltage (Vc) is almost equal to the supply voltages because the transformer primary coil resistance is only 18.4 ohms.
- The total dc current is unaffected by an ac input signal; therefore, the amplifier is a class A operation.
- Output transformer T1 matches the low impedance of the load resistor (R5) to the high output impedance of the collector.
- With no ac input signal, no current flows in the load resistor (R5) because only ac signals can be coupled through a transformer.

NOTES

Exercise 2 – AC Voltage, Current, and Power Gains

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to identify single-ended power amplifier ac characteristics by determining ac voltage, current, and power gains. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- Due to the class A operation, there is no distortion or clipping between the input and output
- Calculation of average ac power requires the conversion of the peak-to-peak (pk-pk) ac voltages to root mean square values (rms):

$$V_{rms} = (V_{pk\text{-}pk} \text{ x } 0.707) /2$$

- The average input ac power to the amplifier (P_i) is the product of the rms values of the ac voltage (V_i) an current (I_i) at the base of Q1:

$$P_i = V_i \text{ x } I_i$$

- The output power is the power consumed by load resistor R5. It is the product of the rms voltage drop across (V_o) and rms current through (I_o) R5:

$$P_o = V_o \text{ x } I_o$$

- Another form of the power formula may be used when voltage and resistance are known:

$$P_o = V_o^2 / R5$$

- Amplifier voltage, current, and power gains are the ratios of the output values to the input values:

Voltage Gain	$A_v = V_o / V_i$
Current Gain	$A_i = I_o / I_i$
Power Gain	$A_p = P_o / P_i$

- Power gain is also equal to the product of the voltage gain and current gain:

$$A_p = P_o / P_i = (V_o \text{ x } I_o) / (V_i \text{ x } I_i) = A_v \text{ x } A_i$$

- The voltage gain of a power amplifier is low, but the power gain is high because the current gain is very high.

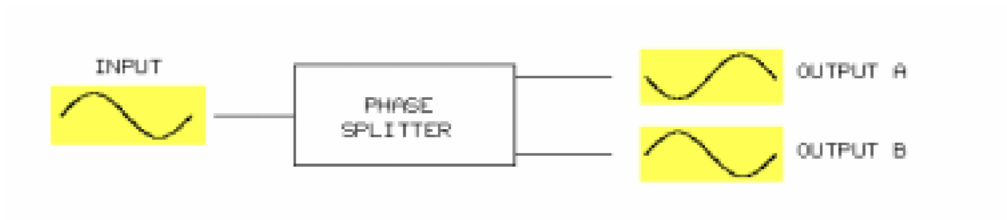
NOTES

UNIT 3 – PHASE SPLITTER

UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate and describe the operation of a transistor phase splitter circuit by using dc and ac measurements.

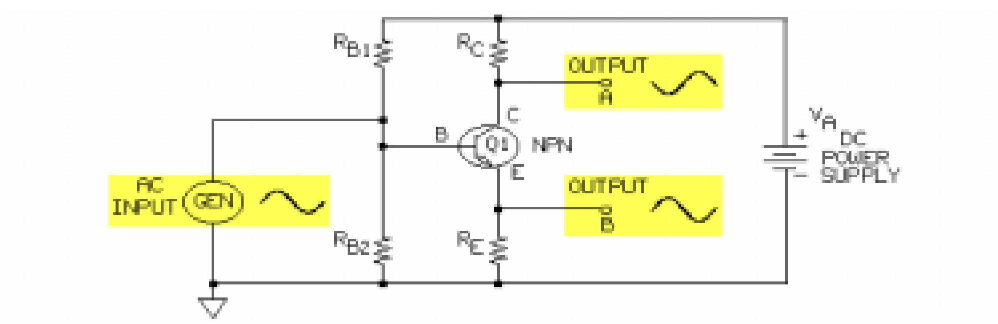
UNIT FUNDAMENTALS



A block diagram of a phase splitter is shown above.

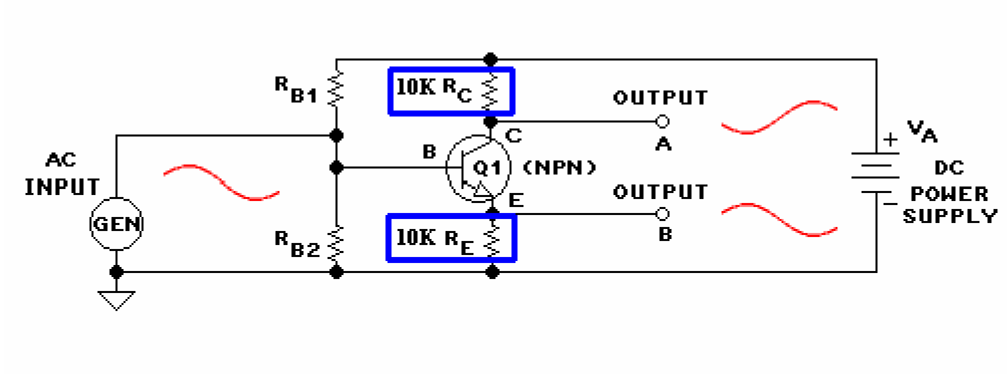
A phase splitter can be a transformer or a transistor circuit.

A phase splitter is a circuit that receives a single input signal and provides two equal amplitude output signals that are 180º out of phase



A **transistor phase splitter** circuit is shown above. The input is at the base of Q1, and the outputs are at the Q1 collector (C) and emitter (E) terminals. The voltage divider circuit (R_{B1} and R_{B2}) across the dc power supply sets a base voltage (V_B) that maintains a stable forward bias for Q1.

Because the voltage divider circuit forward biases the transistor (Q1), the phase splitter operates as a class A amplifier



In a transistor phase splitter circuit, the emitter resistor (R_E) and collector resistor (R_C) are equal. When R_C and R_E are equal, the voltage drop across the collector circuit equals the emitter circuit voltage drop.

Because the emitter (R_E) and collector (R_C) resistors are equal, the voltage gains at outputs A and B of the transistor phase splitter are equal and slightly less than 1.0.

To summarize, a transistor phase splitter is a common-emitter circuit that converts the input signal into two output signals that are 180° out of phase with peak-to-peak voltages essentially equal to the input signal.

NEW TERMS AND WORDS

transistor phase splitter - a transistor circuit that generates two equal signal out of phase, from a single input signal.

EQUIPMENT REQUIRED

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

NOTES

Exercise 1 – Phase Splitter DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to measure dc operating voltages and currents by using a typical transistor phase splitter circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- In transistor circuits, the emitter and collector currents are essentially equal because the base current is very small.
- In a phase splitter circuit, the emitter and collector resistors (R3 and R4) have the same value.
- Because the emitter and collector currents are almost equal, the collector resistor (R3) and the emitter resistor (R4) voltage drops are about equal.
- Since emitter and collector circuit voltage drops are about equal, the ac waveforms at each terminal (A and B) will have the same magnitude.
- No-signal and signal total circuit currents are the same; therefore, the phase splitter is a class A amplifier.

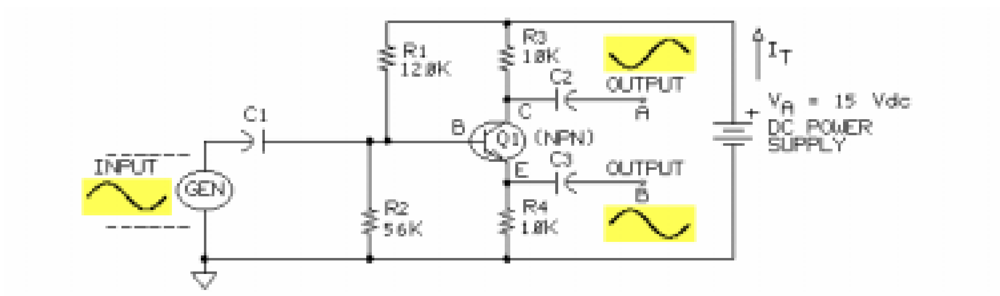
NOTES

Exercise 2 – Voltage Gain and Phase Relationships

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to measure phase splitter voltage gain and phase relationships by using a typical phase splitter circuit. You will verify your results with an oscilloscope and a multimeter.

DISCUSSION



- The input signal is in phase with output signal B at the emitter.
- The input signal is out of phase with output signal A at the collector.
- The ac currents at the input, emitter, and collector are in phase.
- When calculated from circuit resistances, the gain of the phase splitter circuit is less than one even through the measured gain appears to equal one.

$$A_V \text{ (output B)} = R_E / R_E + r_e)$$

- The outputs at the emitter and collector are equal in magnitude but 180 degrees out of phase.

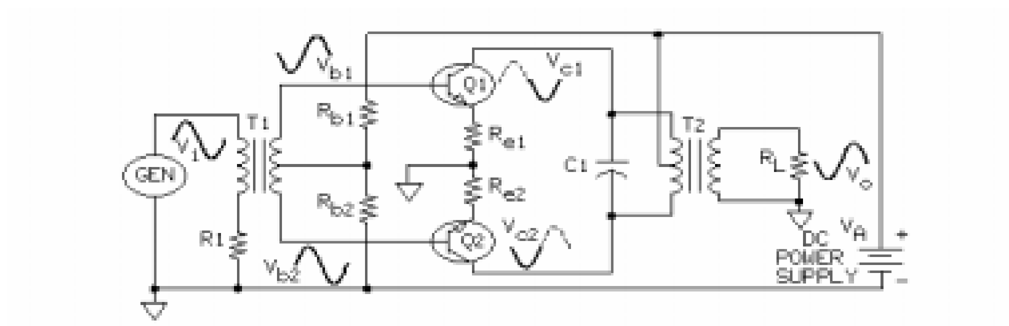
NOTES

UNIT 4 – THE PUSH-PULL POWER AMPLIFIER

UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a typical push-pull power amplifier by using ac and dc measurements.

UNIT FUNDAMENTALS



A **push-pull power amplifier** circuit is shown. It offers greater power gain and better efficiency than a single-ended amplifier circuit does.

The two transistors (Q1 and Q2) of a push-pull power amplifier require input signals at the base that are equal in amplitude but 180º out of phase.

A push-pull transistor amplifier can use a center-tapped transformer (T1), as shown above, or a phase splitter circuit to provide the two equal 180º out-of-phase input signals.

Because the ac inputs to each transistor are 180º out of phase and the dc bias is near the cutoff point, each transistor conducts during opposite halves of the input signal (V_i). The transistor collector signals are combined into one output signal (V_o) by the output transformer (T2).

Crossover distortion of the output signal is prevented by each transistor being biased near the cutoff point.

Because each transistor operates as a class AB amplifier, the output (V_o) of the push-pull amplifier is a class A signal.

The power gain of the push-pull power amplifier is high because the current gain is very high; the voltage gain is low (less than 1.0).

NEW TERMS AND WORDS

push-pull power amplifier - a circuit with two similar transistors connected to operate with equal magnitudes but opposite phases. The outputs of each component are combined.
Crossover distortion - a signal that is distorted near the zero crossing point not affected at the peaks and valleys.

EQUIPMENT REQUIRED

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

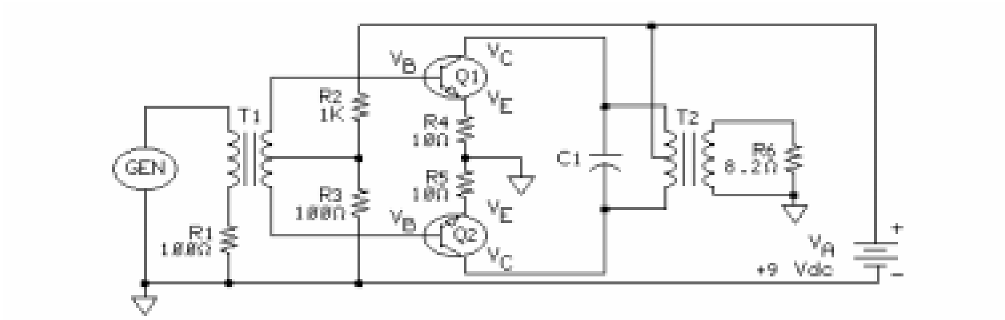
NOTES

Exercise 1 – DC Operation

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to demonstrate the dc operation of a push-pull power amplifier by using a typical push-pull power amplifier circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION



- Two class AB amplifiers connected back-to-back in a common emitter configuration form a push-pull power amplifier
- Base resistor R2 and R3 form a voltage divider circuit to provide the base voltage for forward biasing the transistors.
- The voltage drop across each transistor is slightly less than the power supply voltage
- The transistors are biased near the cutoff point so that the collector power dissipated is minimum under no-signal conditions.
- Collector current for each of the two class AB transistors flows only during a portion of the input signal; consequently, the total dc circuit current is affected by an ac input signal.
- Transformer T2 matches the relatively high output impedance of the transistors to the low impedance of the load.

NOTES

Exercise 2 – AC Voltage and Power Gains

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to measure push-pull power amplifier voltage and power gains by using a typical push-pull power amplifier circuit. You will verify your results with an oscilloscope.

DISCUSSION

- The input transformer (T1) is used as a phase splitter to develope two signals that are equal in amplitude but opposite in phase to transistors Q1 and Q2.
- Transistor Q1 amplifies the negative half of the input signal, and transistor Q2 amplifies the positive half.
- These half-signals from the transistors are then combined in output transformer T2 to restore the sine wave, which is 180° degrees out of phase with the input signal to T1.
- A small collector current is needed to flow at all times to prevent a type of waveform distortion called cross-over distortion.
- Transistors Q1 and Q2 conduct for more than 180° but less than 360° of the input signal, permitting continuous collector current.
- The power gain is high, but the voltage is not.
- These transistors are considered class AB.

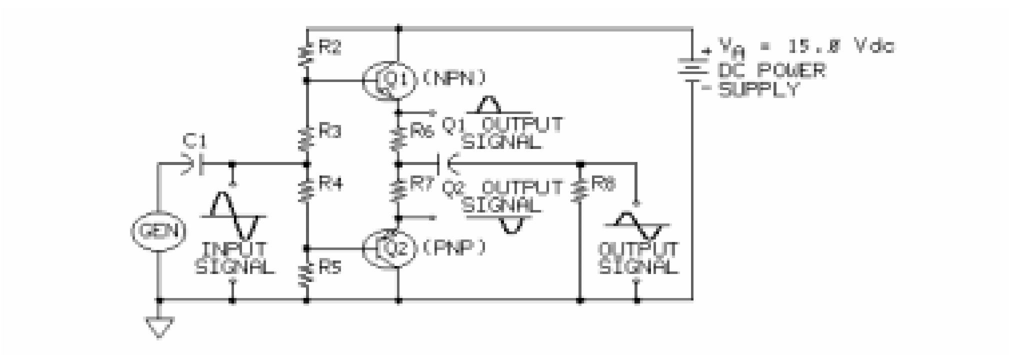
NOTES

UNIT 5 – THE COMPLEMENTARY POWER AMPLIFIER

UNIT OBJECTIVE

At the completion of this unit, you will be able to demonstrate the operation of a complementary power amplifier by using measured circuit conditions.

UNIT FUNDAMENTALS



A complementary power amplifier circuit is shown.

A complementary power amplifier consists of an NPN transistor and a PNP transistor connected in series across a dc power supply. The transistors are configured in common collector circuits.

Each transistor operates as class AB, resulting in an output from the complementary power amplifier that is nondistorted.

NPN and PNP transistors have **complementary symmetry**; the biasing is arranged so that the input signal polarity needed to turn on the NPN is opposite that needed for the PNP.

Complementary power amplifiers have high input impedance, low output impedance, high power gain, and good efficiency.

NEW TERMS AND WORDS

***complementary symmetry* -** the property of two transistors in which the polarity of an input signal needed in one transistor is opposite to that needed in the other.
***matched transistors* -** transistors that have almost identical characteristics (betas, leakage currents, and other parameters).
***matched transistors* -** transistors that have almost identical characteristics (betas, leakage currents, and other parameters).

EQUIPMENT REQUIRED

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

NOTES

Exercise 1 – DC Operation

EXERCISE OBJECTIVE

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

DISCUSSION

- A complementary power amplifier has an NPN transistor (Q1) and a PNP transistor (Q2) connected in series in a common-collector configuration.
- About half the power supply voltage (V_A) is across each transistor.
- Both transistors are biased to have Q-point that is very close to the cutoff point.
- An ideal complementary power amplifier requires two matched transistors.
- The dc biasing permits each transistor to be turned on for slightly more than 180 degrees of the input signal; this is class AB operation.

NOTES

Exercise 2 – AC Voltage and Power Gains

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine voltage and power gains by using a typical complementary power amplifier circuit. You will verify your results with a multimeter and an oscilloscope.

DISCUSSION

- The NPN Q1 transistor conducts during the positive half-cycle of the input signal (V_i).
- The PNP Q2 transistor conducts during the negative half-cycle of the input signal (V_i).
- Each transistor conducts for a slightly more than 180 degrees of the input signal, producing an output signal with no cross-over distortion; this is class AB operation.
- The output signal is in phase with the input signal.
- The high power gain is the product of a voltage gain less than 1.0 and a very high current gain.

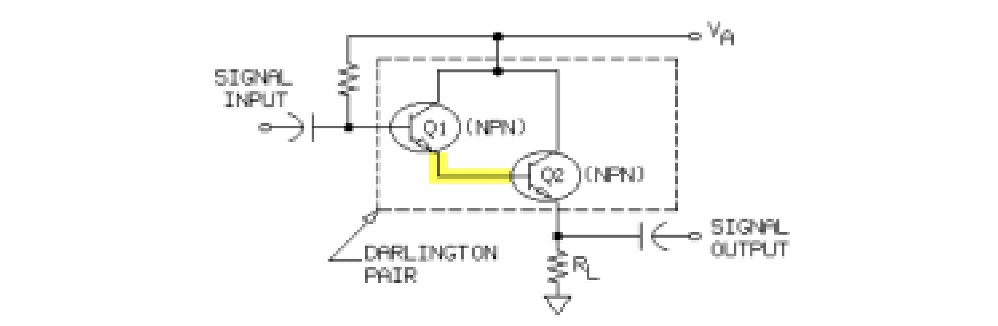
$$A_p = A_v \text{ x } A_i$$
$$P_{in} = V_i \text{ (rms) x } I_i \text{ (rms)}$$
$$\text{where: } I_i \text{ (rms)} = V_{R1} \text{ (rms) / R1}$$
$$P_{out} = V_o \text{ (rms) x } I_o \text{ (rms)}$$
$$\text{where: } I_i \text{ (rms)} = V_o \text{ (rms) / R6}$$

UNIT 6 – THE DARLINGTON PAIR

UNIT OBJECTIVE

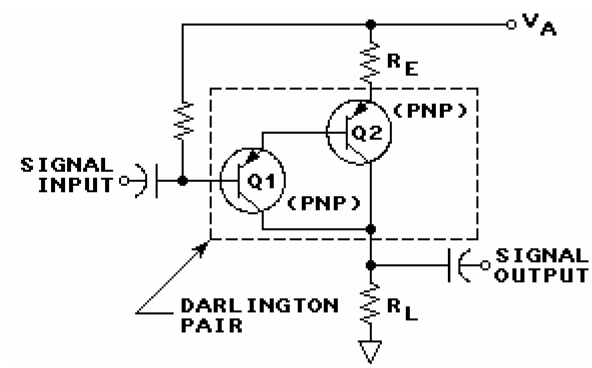
At the completion of this unit, you will be able to demonstrate the operation of a typical Darlington pair by using measured circuit conditions.

UNIT FUNDAMENTALS



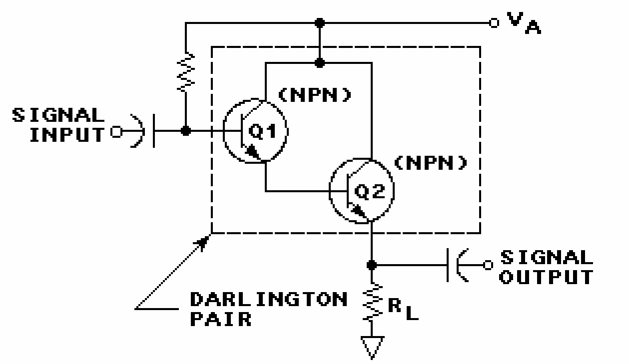
Transistors can be connected in many ways to allow you to take advantage of different characteristics or to make best use of a particular parameter.

A Darlington pair consists of two NPN or PNP transistors (NPN shown) with the emitter of the first stage directly connected to the second stage base.



This circuit shows a PNP Darlington pair in a common emitter configuration.

The Darlington pair acts as a single transistor with an overall current gain (β_D) equal to the product of the individual transistor current gains (β).



The input impedance of a Darlington pair is very large.

When the Darlington pair is connected in a common collector configuration, the output impedance is very small.

The two transistors of a Darlington pair are often mounted in the same case so that both transistors undergo exactly the same changes in temperature and applied voltage.

NEW TERMS AND WORDS

None

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
TRANSISTOR POWER AMPLIFIERS circuit board
Multimeter

NOTES

Exercise 1 – Current Gain Characteristics

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the current gain of a Darlington pair by using measured values. You will verify your results with a multimeter.

DISCUSSION

- A Darlington pair has the emitter of the first stage transistor directly connected to the base of the second stage transistor.
- In a Darlington pair, the Q2 base current (I_{B2}) equals the Q1 emitter current (I_{B1}) or essentially equals the collector current (I_{C1}):

$$I_{B2} = I_{C1}$$

- The Q1 and Q2 betas equal the ratio of the collector and base currents:

$$\beta_1 = I_{C1} / I_{B1}$$
$$\beta_2 = I_{C2} / I_{B2}$$

- The Darlington pair current gain (β_D) equals the Q2 collector current (I_{C2}) divided by the Q1 base current (I_{B1}):

$$\beta_D = I_{C2} / I_{B1}$$

- The Darlington pair current gain (β_D) equals the product of the betas of each stage:

$$\beta_D = \beta_1 \text{ x } \beta_2$$

- If the two transistors in a Darlington pair are very carefully matched to have equal betas, the Darlington pair beta (β_D) equals the square of the transistor beta:

$$\beta_D = (\beta)^2$$

NOTES

Exercise 2 – Input and Output Impedances

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to determine the input impedance of a typical Darlington pair circuit. You will verify your results with a multimeter.

DISCUSSION

- A Darlington pair in a common collector circuit is useful in matching a very high impedance source to a very low impedance.
- The input impedance of a Darlington pair is very high (in the range of 500kΩ to 10MΩ for a small signal transistor).

$$Z_i\,(D) = \beta_1 \text{ x } \beta_2 \text{ x } R5 = \beta_D \text{ x } R5$$

- The input impedance in a common emitter circuit is very low (in the range of 1Ω to 50Ω for a small signal transistor).

NOTES

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. The F.A.C.E.T. computer-based laboratory may be a new environment to some students. Instruct students in the proper use of the F.A.C.E.T. 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 the F.A.C.E.T. 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 your F.A.C.E.T. 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.