LABORATORY WORK BOOK
For The Course
EL-236 Amplifiers and Oscillators

Name : ____________________________

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Year : ____________________________

Dept. : ____________________________

Department of Electronic Engineering
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LABORATORY WORK BOOK

For The Course

EL-236 Amplifiers and Oscillators

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Introduction

"A practical approach is probably the best approach to mastering a subject and gaining a clear insight."

Amplifiers and Oscillators Practical Workbook covers those practical oriented circuits that are very knowledgeable and quite beneficial in grasping the core objective of the subject. These practical solidify the theoretical and practical concepts that are very essential for the engineering students.

This book comprises of two sections. The first section consists of Amplifier. Different classes and configurations of amplifiers are discussed in this section. Both BJT and FET based amplifiers are included in this part of the workbook. Lab session also provides the extensive theory with the practical knowledge.

The second section of the workbook describes the Oscillators. This is one of the basic building blocks of communication field. Comprehensive lab sessions are arranged that covers the practical on oscillators. Different types of oscillators are discussed along with their complete working theory. These circuits provide a great in depth knowledge of the subject.

All of these practical are arranged on the modern electronic trainer boards. Above all this workbook contains a very descriptive and relevant theory about the topics before starting the lab session. Almost all the labs contain exercises for the students to practice.

Amplifiers and Oscillators Laboratory

CONTENTS

Section One

Amplifiers

Lab Session 01

OBJECTIVES

- To determine the classes of operation (Class A, B and C biasing).
- To study the operation of BJT Amplifier.

EQUIPMENT REQUIRED

- Base unit for the IPES system (power supply mod.PSU/EV, module holder structure mod. MU/EV)
- Individual Control Unit
- Mod.SISl/SIS2/SIS3
- Experiment module mod.MCM4IEV
- Oscilloscope
- Multimeter
- Function generator

BASIC THEORY

Classes of Operation

Transistor amplifier circuits can be classified using the general transfer characteristic as shown in figure B 18.6.

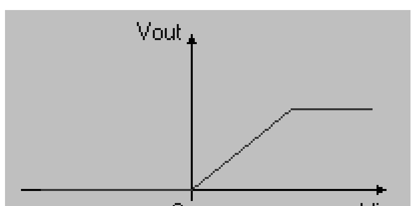


fig. B18.6

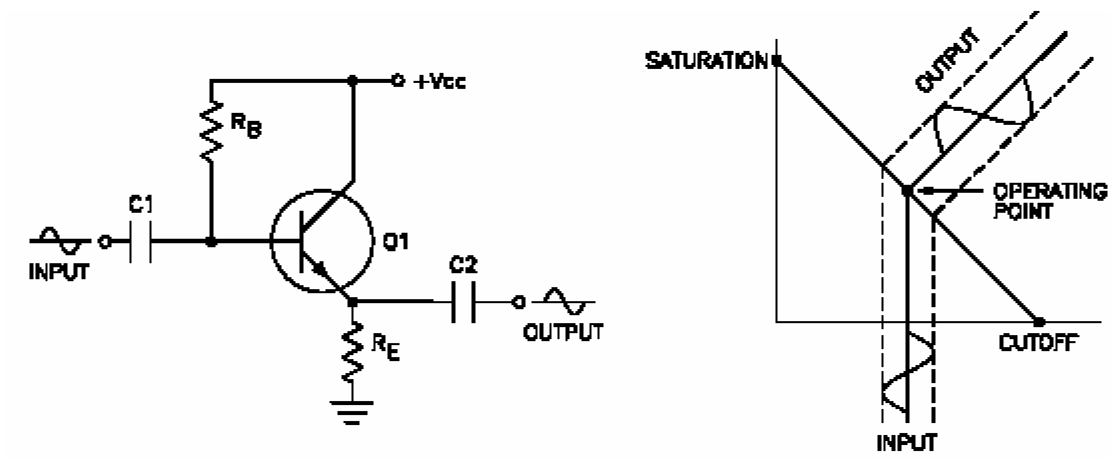
The signals to be amplified are normally time variable (ac). In some applications, only a part of the input wave is to be amplified; this is possible if a suitable point on the characteristic is chosen. The different operating modes can be put into three categories, called "class A", "class B" and "class C"

Class A

The operating point in the class A is located in the center of the straight section of the transfer curve. In this case, if base current excursions (caused by the input signal) stay within the linear region, the wave-form across the output of the amplifier faithfully reproduces that of the input signal. It follows that the collector current flows for the entire duration of the input signal cycle, and its average value is constant, and equal to that in the Q state.

As the linear range over which the base and collector currents can vary is limited, it follows that it is not possible to "extract" all the power possible from the transistor. This max. power corresponds to the max. excursion possible of the collector current, i.e. from zero to saturation. The result is that the efficiency of the amplifier, defined as the ratio between the power supplied to the output (Po) and the power taken from the supply ($Vcc.Ic_Q$), is very low.

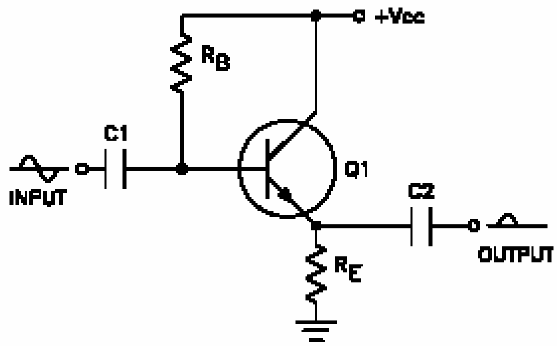
In the Class A mode, the transistor is made to operate continuously for the entire cycle of the input signal, for a common collector amplifier. (The common collector amplifier is used as an example of class because the voltage gain is 1 and there is no phase inversion between input and output. Class A has the bias point, the operating point, located halfway along the load line. This means that the entire input signal waveform will not put the transistor into cut-off or saturation.

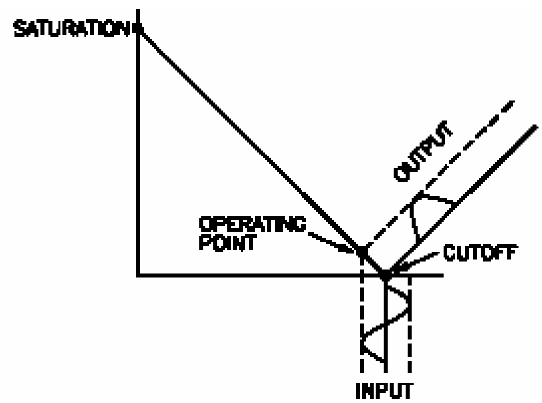


Class B

In this case, the Q point is placed close to the cut-off point of the transistor, so the collector current is very low (with no input signal). In the presence of a signal the current flows only during the positive part of the applied signal. The negative part of the input signal is less than the cut off value, and causes a complete cut-off of the collector current. With an alternating signal, the collector current flows only for half a period, i.e. 180 degrees. This angle is called the conduction angle. To reconstruct the signal requires two transistors, conduct alternately: one for each half cycle. The typical efficiency of the class B operation is higher than class A.

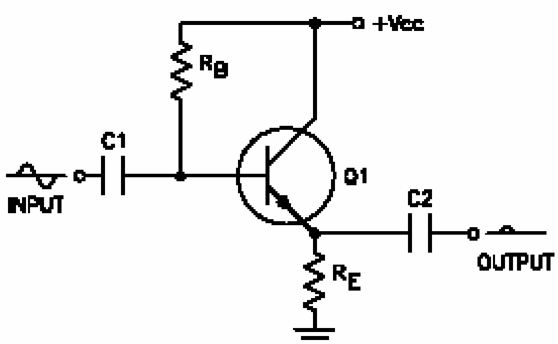
In Class B operation, the transistor operates during only 50 percent of the duration of the input signal. The bias point, the operating point, is placed so that during the negative alternation, the transistor is cut off.

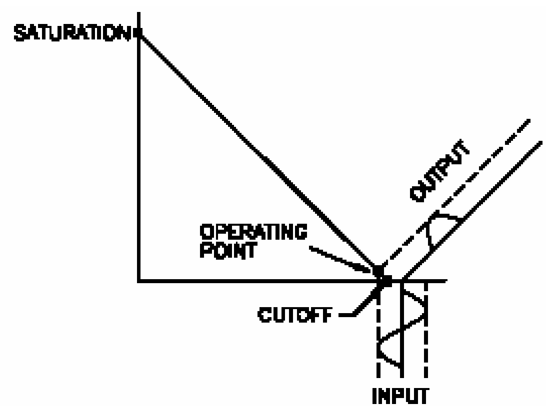




Class C

In class C, the operating point is moved even lower than the cut-off point. The transistor supplies an output signal only if the input signal is at some point sufficiently large to exceed the cut off threshold. The conduction angle is further reduced compared to class B, being even less than 180 degrees. The collector current pulses are very narrow, with a duration less than half a period long. Although a class C amplifier produces a huge distortion in the output signal, it can operate with high efficiency.





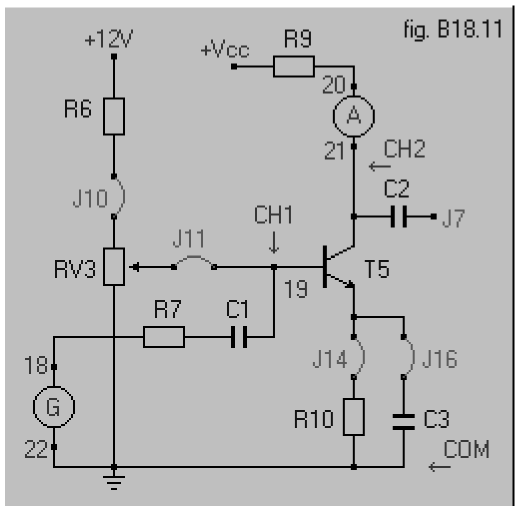
In Class C operation, the operating point is dropped further. As shown, the output signal is only developed for less than 50 percent of the input signal.

Class C is the most efficient mode of operation, because the transistor is turned OFF most of the time. However, the output signal is distorted. Class A operation is the least efficient, but there is no distortion. For the operation of an oscillator, distortion is not a factor. The transistor amplifier is only used to feed back the signal to its input; the entire output signal is not needed. Therefore, most oscillators operate Class B or C to increase efficiency.

PROCEDURE

➢ ***Class A amplifier***

1. Connect jumpers J10, J11, J14, J16, and the ammeter between points 20 and 21 as in figure BI8.11.



2. Adjust the function generator for a sine signal with amplitude 0mV peak-to-peak and 1 KHz-frequency.
3. Set Vcc = 20 V and adjust R V3 to obtain I_{CQ} ~ 10 mA.
4. With no signal from generator G, the channel 2 of the oscilloscope displays a constant voltage equal to V_{CEQ} + R10. I_{CQ}

CH2 = ________________

5. Progressively increase the amplitude of the signal supplied by the generator, until there is 50 mV peak-to-peak on channel 1 of the oscilloscope.
6. Note the output voltage on channel 2.

CH2 = ________________

What is the behavior of the output signal?

____

Due to the signal applied to the Base of the transistor, we can say that the instantaneous Q point "moves" along the load line, producing a variable signal Vce across the output. The excursions of the Q point on the load line are symmetrical with respect to the bias values V_{CEQ} and I_{CQ}.

7. Move the channel 2 of the oscilloscope to the other side of capacitor C2, and display the output signal again.

You will see that capacitor C2 enables us to decouple the output signal, that is to remove the dc component V_{CEQ}

8. Increase the amplitude of the input signal, and note the behavior of the output signal on the oscilloscope.

When the input voltage increases, the output signal has distortions, due to the fact that the excursions of the Q point then reach the saturation regions

To obtain the max. signal without distortion at the output, what should V_{CEQ} be, in theory?

____

- ***<u>Amplifiers in class B and C</u>***

9. In the circuit of fig. B 18.11, adjust I_{CQ} to about 5 mA by means of RV3.
10. Adjust the function generator for a sine wave signal with 50mV amplitude peak-to-peak and 1KHz frequency.
11. Set channel 2 of the oscilloscope to DC.
12. Slowly increase the bias voltage V_{CEQ} and reducing I_{BQ}, observing the behavior of the output voltage at the collector.

How does the displayed signal change?

____

This is because the transistor starts entering cut-off. If I_{BQ} continues to decrease, you will see a signal corresponding only to the positive half-waves of the input signal, which may raise the Q point above the cut-off region of the transistor. The circuit now operates in class B, and so only the positive half waves of the input signal are amplified.

13. Reduce I_{BQ} again, and check the voltage across the transistor.

For a low value of I_{BQ} the output signal can become zero, if the input signal does not have sufficient amplitude to take the transistor outside the cut-off region. If the circuit amplifies only a small part of the positive half wave conduction angle < 180°), then the operation is in class C.

CONCLUSION

Lab Session 02

OBJECTIVES

1. Determine the effects of input signal frequency on capacitor coupled common emitter amplifiers.
2. Determine the effects of input impedance on common emitter amplifier gain.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card: PC130-29
- Function Generator
- Oscilloscope
- Multimeter

INTRODUCTION

Frequency effects on amplification

The function of the input capacitor in an amplifier circuit is to pass the AC variations of the input signal and block the DC component. Figure 1 depicts a typical amplifier circuit. The three parts of the figure illustrate the actual circuit, the DC equivalent, and the AC equivalent. Due to the inherent differences between AC and DC, each will be affected differently by the same component.

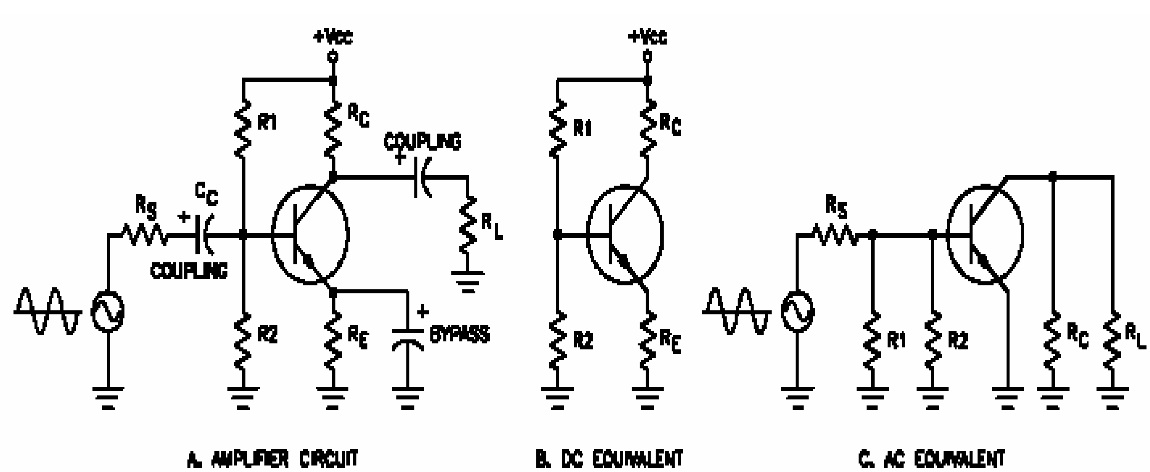


Figure 1. Amplifier Circuit

The coupling capacitor's function is to pass an AC signal from one point to another. In the case of Figure 1A, the signal is passed from R5 through CC to the base of Q1. For that to happen, the capacitive reactance of the coupling capacitor must be very small compared with the resistance of R5. The size of the coupling capacitor used depends upon the lowest frequency that is to be passed to the amplifier. As a rule, the capacitive reactance must be equal to or less than 10% of the resistance of R5. The input coupling capacitor is in series with the base-emitter junction of the transistor. The transistor amplifies only the signal felt on the base. Any signal voltage that is dropped over the coupling capacitor is lost as far as the transistor is concerned. The coupling capacitor, due to capacitive reactance, will have a voltage drop at some frequencies. That occurs because capacitors exhibit low reactance at high frequencies and high reactance at low frequencies.

As an example, if a coupling capacitor has a value of 5 μF, the amount of capacitive reactance it offers to an incoming signal depends upon the frequency of the signal. If the signal has a frequency of 1000 Hz; the capacitor will offer 31 ohms of reactance. Increase the signal frequency to 100 kHz, and the reactance decreases to .32 ohms. On the surface, that may not appear as much resistance, but many times, signal strength is measured in micro volts with currents measured in micro amps. When dealing with such small signals, even a small reactance can have an effect. It is because of that fact that capacitive coupling affects the lower frequencies applied to an amplifier. We can say that the capacitive coupling limits the low frequency response of the amplifier.

The transistorized amplifier circuit has limits to the frequencies that it can amplify. Not only are reactive components, such as capacitors and inductors, affected by frequency, but so are the transistors themselves. As each component is affected differently by frequency, amplifier circuits are designed to amplify only a range or band of frequencies. The three major categories of amplifiers are audio amplifier, RF amplifier, and video amplifier.

Audio amplifiers are designed to amplify frequencies between 10 Hz and 20 kHz. RF amplifiers are designed to amplify frequencies between 10 kHz and 100 kHz. The RF in RF amplifier stands for Radio Frequency. Because there is a large band of high frequencies in the RF range, one RF amplifier circuit cannot amplify the entire range. Video amplifiers are designed to amplify signals from 10 Hz to 6 MHz. Because the band of frequencies is so large, they are also referred to as wideband amplifiers. Signals that are in the range of an amplifier circuit are reproduced with little change. The range of frequencies that can be amplified is called the amplifier's frequency response. If the signal frequency is in the range of the amplifier circuit, there is little, if any, difference between the input and output signals, other than amplitude. If the signal frequency is out of the range of the amplifier, then the signal is, at best, distorted, or at worst, not passed at all.

Amplifier gain

There are two types of gain to be covered, amplifier gain and stage gain. The discussion will begin with amplifier gain. The amplifier gain of a transistor is fixed over a wide range of frequencies by bias. Its method of calculation is simple. First, measure the AC voltage from the collector to the emitter (V_{CE}). Next, measure the AC voltage from the base to the emitter (V_{BE}). The final step is to divide the V_{CE} by the V_{BE} . The resulting amplifier gain is relatively unaffected by signal frequencies changes or changes in the output impedance of the previous stage. The gain of an amplifier is the comparison of the collector-emitter voltage to the base-emitter voltage of an amplifier. The formula for calculating amplifier gain is:

$$\text{Amplifier gain} = \frac{E_{CE}}{E_{BE}}$$

In essence, it is the gain of the transistor only, excluding all external components.

The stage gain of an amplifier is sensitive to changes in frequency or impedance. Stage gain is calculated by dividing the AC voltage at the output of an amplifier by the AC voltage coming from the previous stage or function generator. Stage gain of an amplifier will decrease under any conditions in which the full AC voltage from the previous stage does not reach the base of the transistor amplifier. The stage gain of an amplifier circuit is a comparison of the input voltage and the output voltage. The formula for calculating stage gain is:

$$\text{Stage gain} = \frac{E_{OUT}}{E_{IN}}$$

The stage gain of an amplifier is the amplification ability of the entire circuit, from input coupling capacitor to output coupling capacitor.

Impedance effects on amplification

When an amplifier is designed, two facts must be considered. First, if a signal is changed in any way, there is a cost. That means if the signal amplitude, frequency, or wave shape is changed or altered, there may be a loss in signal strength or fidelity. Second, a circuit consumes power. There is a drive in electronics to make circuits and equipment as efficient as possible. The more efficient an electronic circuit or device, the less wear on electronic components, the less power that has to be supplied, and the less cooling that has to be considered.

The more efficient a device, the less power it consumes. One of the greatest losses of power is caused by the impedance differences between the output of one circuit and the input of another. An analogy that may help explain an impedance difference, or mismatch, is a four lane highway that is reduced to two lanes. When that happens, traffic slows, or becomes less efficient. If the two lane road has a higher speed limit than the four lane road, the efficiency remains the same. The same effect can be found in electronics by matching the output impedance of one circuit or device to the input impedance of another circuit or device.

In this experiment, you will investigate how signal frequency and input impedance affect an amplifier. You will measure voltages in a transistor circuit at various input impedances and frequencies. You will draw conclusions from your results.

EXPERIMENT

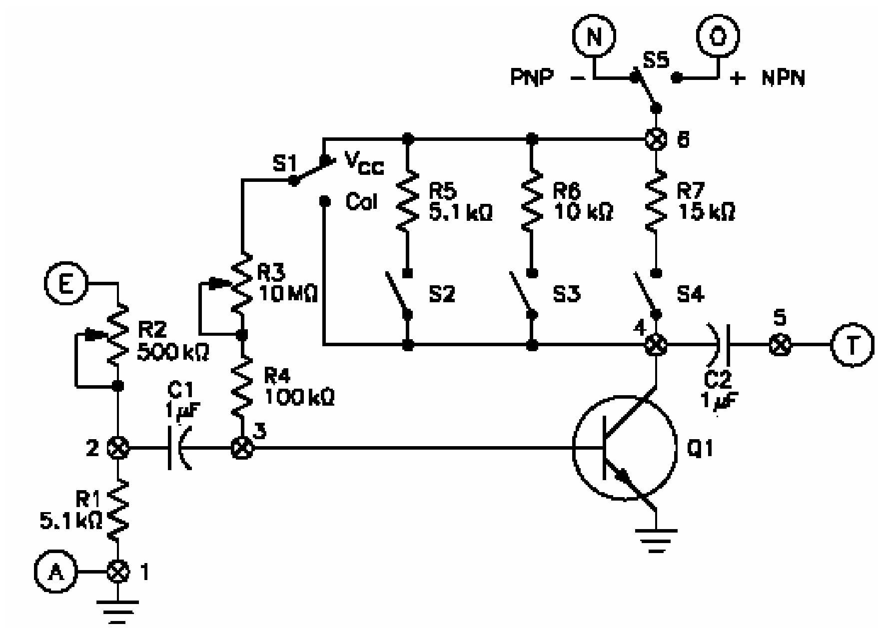


Figure 2. Nida Model PC130-29

PROCEDURE

1. Set the NEGATIVE and POSITIVE SUPPLY controls to OFF, and insert PC130-29 into the PC1 connectors. Insert a 2N3567 NPN transistor into the Q1 socket of PC130-29. Press the console POWER switch to ON.
2. Set PC switch S1 to VCC , S5 to NPN, S2 UP (closed), and S3 and S4 DOWN (open).
3. Adjust R2 for 40 Kilo-ohms using a multimeter (pin E to TP2).
4. Adjust the POSITIVE SUPPLY control to +15 V and set the PC1 DC POWER switch to ON to establish the circuit of Figure 3.

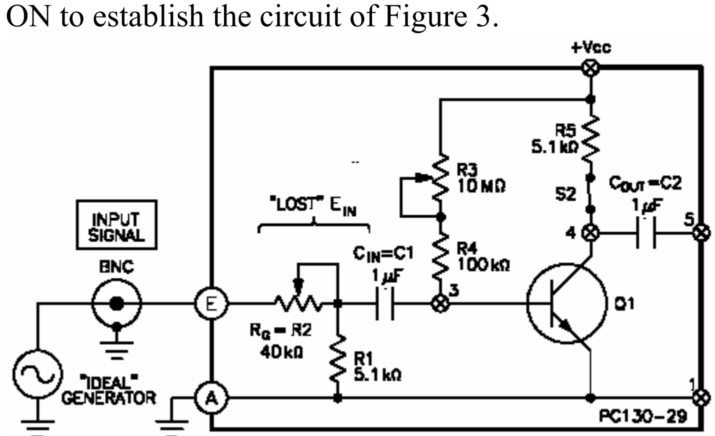


Figure 3. Circuit Connections to Test the Effect of R_G , C_{IN}, C_{OUT}, and Frequency on Amplifier Performance

5. Connect a DC voltmeter across Q1 collector to emitter (TP4 to TP1) and adjust R3 until 5 VDC is measured.
6. Set the function generator to ON and adjust the controls for SINE WAVE output at 1 kHz.
7. Connect the function generator to the test console's PC1 INPUT BNC.
8. Adjust the output of the function generator for 2 V measured at PC130-29 pin E (pin E to TP1). This is the E_{IN}. Fill in the E_{IN} block for each condition in Table 1.
9. Measure E_{BE} (TP3 to TP1), E_{CE} (TP4 to TP1), and E_{OUT} (TP5 to TP1), using the oscilloscope. Record the results in Table 1 for the condition of FREQ $_{IN}$ equals 1kHz.
10. Adjust the generator frequency to 500 Hz. Measure E_{IN}, using the oscilloscope. If necessary, adjust the output of the function generator to maintain an E_{IN} of 2 V.
11. Measure E_{BE}, E_{CE}, and E_{OUT}, using the oscilloscope. Record the results in Table 1 for the condition of FREQ IN equals 500 Hz.
12. Repeat Steps 10 and 11 for each frequency listed in Table 1. Make sure E_{IN} is held at the value measured in Step 8 for the input frequency setting.
13. Determine the stage gain (AV STAGE) for each condition in Table 1. Divide E_{OUT} by E_{IN} and record the results in the AV STAGE column in Table 1.

Table 1. Effects of Frequency on a Capacitive Coupled Input and Output Amplifier

Conditions: FREQ IN	E_{IN} (peak to peak)	E_{BE} (peak to peak)	E_{CE} (peak to peak)	E_{OUT} (peak to peak)	A_V STAGE ($E_{OUT} \div E_{IN}$)	A_V AMP ($E_{CE} \div E_{BE}$)
1 kHz						
500 Hz						
100 Hz						
50 Hz						

14. Determine the amplifier gain (AV AMP) for each condition in Table 1. Divide E_{CE} by E_{BE} and record the results in the AV AMP column on Table 1.

Notice that the amplifier gain is somewhat the same for each frequency. The difference is due to the transistor itself. Also notice that the stage gain decreases as the frequency decreases. Look at the columns for E_{CE} and E_{OUT}. The reason there is no decrease in E_{OUT} across C2 is that there is no load applied to the circuit.

15. Set the PC1 DC POWER switch to OFF and set PC switch S2 DOWN (open). Connect an ohmmeter across TP6 and TP3 to measure RB. Record the results below.
RB MEASURED = ____________________

Return S2 to the UP (closed) position.

16. Remove the function generator connection to the PC1 INPUT BNC. Connect an ohmmeter across PC resistor R2 (card PIN E to TP2). Adjust R2 to approximately 50 kilo-ohms. Remove the ohmmeter. Set the PC1 DC POWER switch to ON and reconnect the function generator to the PC1 INPUT BNC.
17. Connect the oscilloscope to E_{OUT} (TP5 to TP1). Set the generator to SINE WAVE at 10 kHz. Adjust the function generator OUTPUT LEVEL ADJUST until E_{OUT} equals 3 V_{PP}. (Adjust the generator attenuation buttons as necessary.)
18. Measure E_{IN} (pin E), E_{BE} (TP3), and E_{CE} (TP4) with the oscilloscope and record the results in Table 2 for the condition of R_G = 50 kilo-ohms.
19. Set the PC1 DC POWER switch to OFF, and repeat Steps 16 through 18 for each R_G setting indicated in Table 2. Maintain 3 V_{PP} E_{OUT} for each R_G setting.

Table 2. Effects of R_g on a Capacitive Coupled Input and Output Amplifier, Freq = 10 kHz

Conditions: R_G VALUE	E_{IN} (peak to peak)	E_{BE} (peak to peak)	E_{CE} (peak to peak)	E_{OUT} (peak to peak)	A_V STAGE ($E_{OUT} \div E_{IN}$)	A_V AMP ($E_{CE} \div E_{BE}$)
50 kΩ						
100 kΩ						
150 kΩ						
200 kΩ						
300 kΩ						

20. Calculate A_V STAGE and A_V AMP.

Notice that the amplifier gain remained about the same as R_G was increased; however, the stage gain decreased!

21. De-energize the test console and all test equipment.
22. Return all test equipment, cables, tools and experiment cards to their proper storage locations.

CONCLUSIONS

What did you learn about the effects of signal frequency and input impedance on transistor amplifiers?

1. Does input signal frequency have a large effect on stage gain? YES _______ NO ________

2. Does input impedance have an effect on stage gain? YES _______ NO ________

SUMMARY

- The coupling capacitor:
  Passes the AC signal from the previous stage.
  Blocks DC voltages from the previous stage.
  Has a high resistance at low signal frequencies and a low reactance at high signal frequencies.
- Amplifier gain:
  Is fixed over a wide range of frequencies by bias.
  Is affected only slightly by changes in signal frequency.
- Stage gain
  Stage gain is greatly affected by changes in input impedance.
  The greater the input impedance, the lower the stage gain.
- The greatest efficiency in signal transfer occurs when the output impedance of one circuit matches the input impedance of the next circuit.
  The point of greatest efficiency is when the power out of one stage equals the power developed over the input resistances of the next stage.
- The greatest voltage gain occurs when the input impedance is ten times greater than the output impedance of the circuit developing the signal.

EXERCISES

1. What is the purpose of a coupling capacitor?

   a. Block AC and pass DC
   b. Block AC and block DC
   c. Pass AC and block DC
   d. Pass AC and pass DC

2. A coupling capacitor has a __________ reactance at high frequencies and a __________ resistance at low frequencies.

   a. low, low
   b. low, high
   c. high, low
   d. high, high

3. An amplifier gain is fixed over a wide range of frequencies by ______________ .

   a. input impedance
   b. output impedance
   c. V_{CC}
   d. bias

4. Stage gain is affected the most by _____________ .

   a. input impedance
   b. output impedance
   c. V_{CC}
   d. bias

5. As the input impedance increases, stage gain _____________ .

   a. increases
   b. decreases
   c. stays the same
   d. doubles with every 1 kΩ increase

6. Two circuits are considered the most efficient when ____________ .
   a. voltage is maximum
   b. voltage is minimum
   c. power transfer is equal
   d. current is maximum

7. Voltage gain is the greatest when the ____________ .
   a. output impedance of the previous stage is 1/10 the input impedance
   b. output impedance of the previous stage is 10 times the input impedance
   c. the output impedance of the previous stage is equal to the input impedance
   d. current is maximum

8. If an amplifier circuit has an input signal of 50 mV amplitude and an output signal of 15 V amplitude, what is the stage gain?
   a. 75
   b. 300
   c. 7.5
   d. 30

9. If an amplifier has an E_{CE} of 5 V and an E_{BE} of 10 mV, what is the amplifier gain?
   a. 500
   b. 50
   c. 5
   d. 5000

10. Amplifier gain is the gain of the ____________, and stage gain is the gain of the ____________ .
    a. entire circuit, transistor
    b. transistor, reactive components
    c. transistor, entire circuit
    d. entire circuit, reactive components

Lab Session 03

OBJECTIVES

1. Identify cascade amplification schematic symbols.
2. Describe operating characteristics of cascade amplifiers.
3. Observe normal operation in a cascade amplifier circuit.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-33
- Function Generator
- Oscilloscope
- Multimeter
- Alligator to Alligator Jumper

INTRODUCTION

Throughout electronics, single amplifier circuits (such as the common emitter, common base, and common collector) are seldom found alone in equipment. The vast majority of equipment has several amplifiers connected together to perform a specific function. Within the specific function, each individual transistor circuit is called a stage. In this lesson, you will learn how transistor amplifiers are connected so that much greater levels of signal (voltage) amplification may be obtained.

Cascade Amplifiers

The term **cascade amplifier** refers to the way in which the output of one amplifier is applied to the input of another. In other words, it is a circuit configuration. Simply put, if the output of one amplifier is connected to the input of another amplifier, the amplifiers are said to be connected in cascade. Cascade amplifiers are very common throughout electronics. When several transistor amplifiers are connected together, each individual transistor amplifier is called a **stage**. The stage consists of the transistor and associated components required for normal operation. Therefore, an amplifier section containing five cascade amplifiers would be called a 5-stage amplifier. The term "stage" can be used any time multiple circuits are connected together. As a rule, one amplifier stage is of little use. In previous lessons and experiments, you learned that amplifier gains of between 100 and 300 are possible. In reality, obtaining gains of this magnitude is not easy. While one stage may have an amplification figure in the range of 100 to 300, stability and predictability of signal shape are sacrificed. By using the simple cascade configuration, very high gain is possible without any loss in stability or signal predictability.

The cascade amplifier configuration is obtained by simply connecting the output of one amplifier to the input of the next amplifier. No doubt, your question is, "Why?" In answer, there are two important advantages in doing so: a much larger voltage gain and stability / signal predictability.

First, a much larger voltage gain is obtained by using multiple stages. The resulting gain is not additive; rather, it is the product of the individual gains.

$$A_{VTotal} = A_{V1} \times A_{V2} \times A_{V3}$$

A_V represents the total voltage gain of several stages of amplification, and A_{V1} through A_{V3} represent the gain of each individual stage. Because of this relationship, the gain of an individual stage is not critical. Therefore, designers usually set the gain of the individual stages relatively low. That low gain setting provides the second advantage with cascade amplifiers - stability and signal predictability. If the gain of one amplifier section isn't high enough, more stages are simply added.

Figure 1 illustrates a typical two stage cascade amplifier. The circuit can be easily expanded by taking the output of the final stage and connecting it to the input of another amplifier stage. Gain stable cascade amplifiers usually have gains in the range of 5 to 20. When dealing with a cascade amplifier section containing several stages, the typical gain of one amplifier is around 10. There is an excellent reason for designing output gains of that figure. The final output of any cascade amplifier section is always a multiple of ten. Therefore, if you need a final gain of 1,000,000, then six stages of amplification would be required. Remember, the final amplification figure is the product of each individual stage.

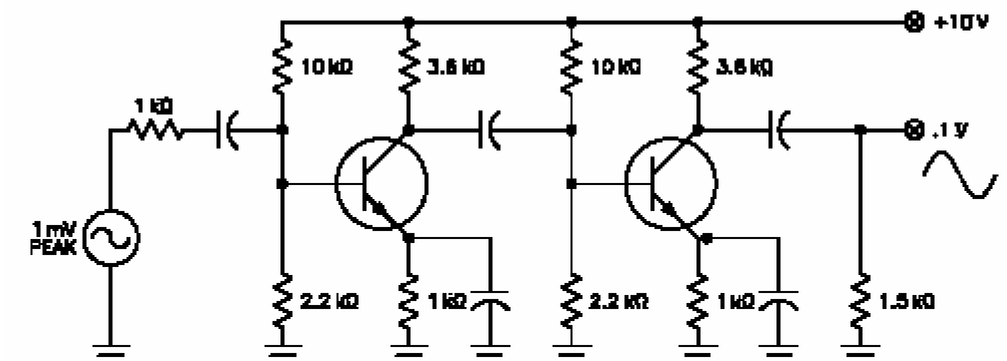


Figure 1. Typical 2 Stage Cascade Amplifier

Cascade amplifiers are RC coupled. The R refers to the collector resistor and the C refers to the coupling capacitor. By using RC coupling, each stage of an amplifier is independently biased. The capacitor isolates the DC voltages from one stage to the next while passing the AC signal. That way, only the AC signal variations are passed from one stage to the next.

EXPERIMENT

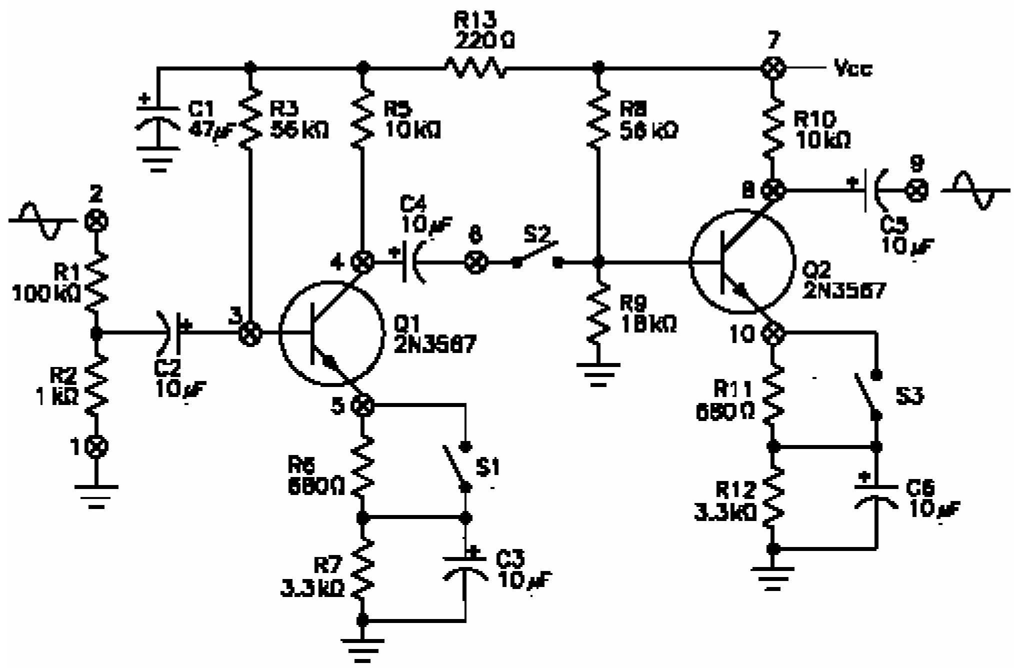


Figure 2. PC130-33 Schematic

PREPARATION

Study PC130-33 and its schematic illustrated in Figure 2. As you can see, it is a two stage cascade amplifier with RC coupling. The AC signal is applied to the base of Q1 via R1 and coupling capacitor C2. Q1's output is applied to the base of Q2 via coupling capacitor C4.

PROCEDURE

1. Set the NEGATIVE and POSITIVE SUPPLY controls to OFF, and turn the console POWER switch to ON.
2. Insert PC130-33 into the PC2 connectors. Set PC switches S1, S2, and S3 to IN. Set the POSITIVE SUPPLY control to +12 V, and set the PC2 DC POWER switch to ON.
3. Connect the function generator to the console's PC1 OUTPUT BNC. Set the generator to SINE WAVE at 1 kHz. Connect the oscilloscope input to PC130-33 Eg input (TP2) and GROUND to TP1. The estimated average gain of each stage is 10. Realize that actual measurements may indicate a large deviation from the estimates without a fault in the system.
4. Adjust the generator output until Eg equals 2 VPP as measured with the oscilloscope.
5. Measure EIN1, EOUT1, EIN2, and EOUT2, using the oscilloscope at the test points indicated on Figure 3. Record the results (in peak to peak values) below

and on Figure 3. Set the oscilloscope input coupling to AC for these measurements.

(TP3) E_{IN1} = ____________ (TP6) E_{IN2} = ____________

(TP4) E_{OUT1} = ____________ (TP8) E_{OUT2} = ____________

6. Determine the A_{V1}, A_{V2}, and A_{VT} of Figure 3 based on the measured data in Step 5. Record the results below and in Figure 3.

$$A_{V1} = \frac{E_{OUT1}}{E_{IN1}} = \_\_\_\_\_\_\_\_\_\_ \qquad A_{V2} = \frac{E_{OUT2}}{E_{IN2}} = \_\_\_\_\_\_\_\_\_\_$$

$$A_{VT} = A_{V1} \times A_{V2} = \_\_\_\_\_\_\_\_\_\_$$

Notice that if you divide EOUT2 by EIN1, you get the same results as if you multiply AV1 by AV2. This is the overall voltage gain.

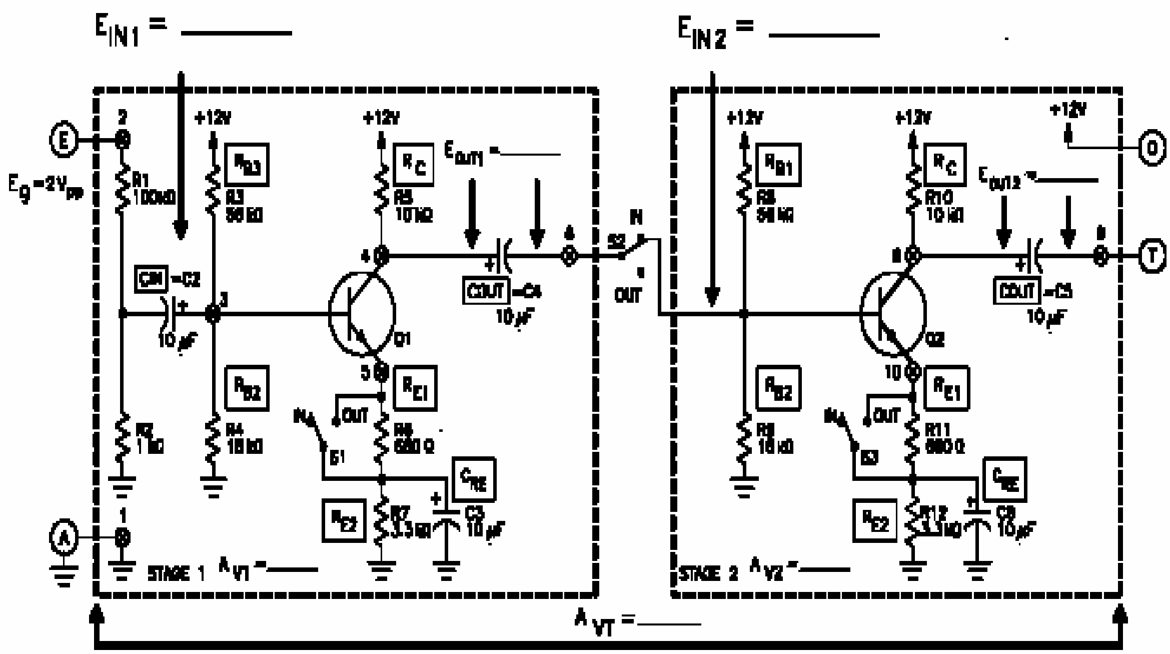


Figure 3. Circuit Connections to Test a 2-Stage RC Coupled Cascade Amplifier System

The signals observed in Step 5 are riding on DC bias voltages. In fact, these signals would not be present except for proper DC bias in the 2 stages. A quick check of amplifier performance is accomplished as indicated in Step 5.

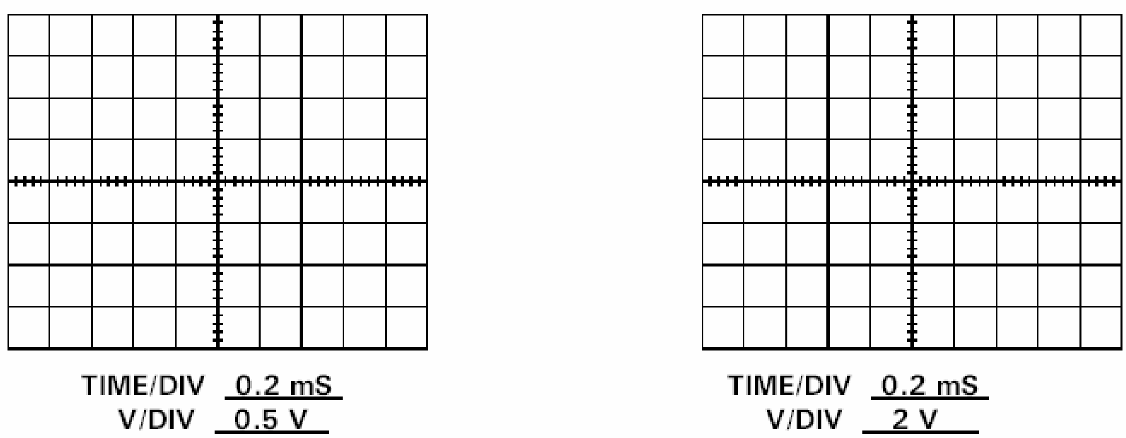
Table 1. Measured DC Bias Voltages in a 2-Stage RC Coupled Amplifier System

CONDITION:	TP3	TP4	TP5	TP6	TP8	TP10
MEASURED						

7. Set the function generator to OFF. Measure the voltages indicated in Table 1 and record the results in the MEASURED row. (Use an oscilloscope set for DC voltage or a multimeter.)
8. Set the function generator to ON. Repeat Step 7 with AC signal present and compare the results to the MEASURED values in Table 1. DC bias may be checked with AC signals present if the AC signals are pure waves and undistorted. By comparing, you should see that the DC bias voltages are the same.

Previous experiments introduced the concept of output limits under large signal conditions. In a cascade amplifier, only the FINAL stage is subject to large output signals. Analysis of the remaining stages for output limits is not necessary.

9. Increase the generator output until EOUT2 clips noticeably on both the + and – alternations, as measured with the oscilloscope (TP8 - output of generator approximately 20 VPP). Draw the resultant waveforms in Figures 4A and 4B – EOUT1 (TP4 to TP1) and EOUT2 (TP8 to TP1). **Make sure the oscilloscope input coupling is set to AC.**



4A. E_{OUT1} (TP4 - TP1) 4B. E_{OUT2} (TP8 - TP1)

Figure 4. Stage 1 and Stage 2 Outputs for Stage 2 Driven to its Output Limits

10. Set PC switch S2 to OUT (open). Connect a jumper wire across PC resistor R1. Adjust the generator output until EOUT1 (TP4 to TP1) clips noticeably on both the + and – alternations, as measured on the oscilloscope. This should be with the amplitude control set to minimum. Draw the resultant waveform in Figure 5.

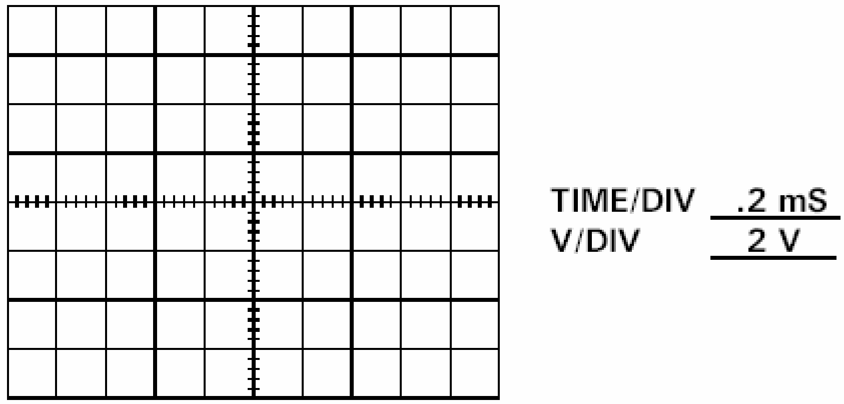


Figure 5. Stage 1 Output Driven to its Limits EOUT1(TP4-TP1)

11. Compare Figure 5 to Figure 4A. When stage 2 is driven to its output limits, stage 1 has a small signal output which will not approach its own limits. In Figure 5, EOUT1 is so large that if switch 2 were closed, damage to the input of stage 2 may occur. **NEVER overdrive a cascade system in such a way that any stage other than the FINAL stage is clipped.** What you did was overdrive stage 1. Remove the jumper across R1 on PC130-33.

12. Set the NEGATIVE and POSITIVE controls to OFF, turn the console POWER switch to OFF, and return all equipment to its designated storage area.

CONCLUSION

1. Did each stage of the amplifier increase the amplitude of the signal? YES _______ NO _______

2. What type of transistors are used on the PC130-33 card? _______________________

SUMMARY

- An amplifier stage in electronics is one transistor and associated circuitry.
- In the cascade amplifier configuration, the output of one stage is connected to the input of the next stage.
- Cascade amplifiers are more stable and signal predictable than a single amplifier.
- Normally, the cascade amplifier gain is between 5 to 20, with 10 being the typical figure.
- The total gain of several amplifier stages connected in cascade configuration is the product of each individual gain.
- In cascade amplifier configuration, each stage is individually biased.
- The input signal of a multistage cascade amplifier causes the output of the final stage. That is called signal flow.

EXERCISES

1. How are two amplifier stages connected in cascade?
   a. The input of one to the output of the other
   b. The output of one to the output of the other
   c. The output of one to the input of the other
   d. The input of one to the input of the other

2. What is the range of gain for a typical stage of a cascade amplifier?
   a. 10 to 300
   b. 5 to 20
   c. 5 to 100
   d. 100 to 300

3. What are the advantages of cascade amplifiers?
   a. Stability, predictability, and high voltage amplification
   b. High voltage amplification, stability, and simplicity
   c. Simplicity, stability, and fair voltage gain
   d. High voltage gain, predictability, and signal flow

4. The gain of a multistage cascade amplifier is determined by __________ .
   a. adding the individual gains of each stage
   b. squaring the individual gains of each stage
   c. multiplying the gain of each individual stage and then dividing by the number of total stages
   d. the product of the gain of all the stages

5. If a multistage cascade amplifier contains 4 stages, each with a gain of 10, what is the total gain of the amplifier?
   a. 10,000
   b. 40
   c. 2500
   d. 10

6. If a multistage cascade amplifier contains 6 stages, each with a gain of 10, what is the total gain of the amplifier?
   a. 10,000
   b. 60
   c. 25000
   d. 1,000,000

7. How are the stages of a cascade amplifier connected?
   a. Directly, with just a wire from the collector of one transistor to the base of the next transistor.
   b. RC, using a coupling capacitor and a collector load resistor
   c. RC, using a coupling capacitor and a base load resistor
   d. RC, using a coupling capacitor and an emitter load resistor

8. What is the purpose of the coupling capacitor?
   a. To pass the AC signal and block the DC voltage
   b. To pass the DC signal and block the AC voltage
   c. To pass the DC signal and block the DC voltage
   d. To pass the AC signal and block the AC voltage

9. Why do amplifier stages in a cascade configured amplifier have a lower gain than an individual transistor amplifier?
   a. Cascade configurations are very inefficient.
   b. To reduce signal loss
   c. To improve stability
   d. Because of the RC coupling

10. The normal range of gain from a cascade configured amplifier is ______ to ________, with ________ being the typical figure.
   a. 1 to 10, 5
   b. 5 to 20, 5
   c. 5 to 20, 10
   d. 10 to 100, 50

11. If a cascade amplifier has a total gain of 100 and an input signal of 100 mV peak-to-peak, what is the amplitude of the output signal?
   a. 1 volt
   b. 10 volts
   c. 100 volts
   d. 1000 volts

Lab Session 04

OBJECTIVES

- Identify three stage audio amplifier schematic symbols.
- Describe the operating characteristics of a three stage audio amplifier.
- Observe normal operation in a three stage audio amplifier circuit.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Cards: PC130-30A, PC130-31, PC130-32
- Function Generator
- Oscilloscope
- Multimeter

BASIC THEORY

In this lesson, you will explore how a three stage audio amplifier functions. Circuit factors to be discussed include voltage, current, and power amplification. The use of block diagrams will be introduced to you.

Three stage Audio Amplifier

Figure 2 is a block diagram of the three stage audio amplifier section. The section consists of three stages connected in cascade. The input block or circuit is a common base transistor circuit that is used as a preamplifier. The input to the transistor is a very small AC signal. In the radio, the signal comes from the IF amplifier; in our discussion and experiment, it is supplied by the function generator. The AC signal is passed by coupling capacitor C1 and applied to the base of Q1. Q1 is biased so that it amplifies any signal applied to its base; it functions as a high gain amplifier. Q1, because of its common base configuration, has a high voltage gain, no phase inversion, low power gain, and low current gain.

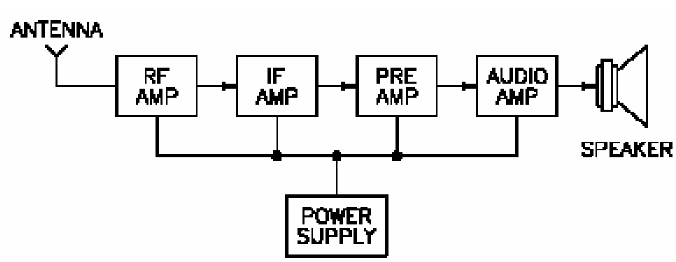


Figure 1. AM/FM Radio - Functional Block Diagram

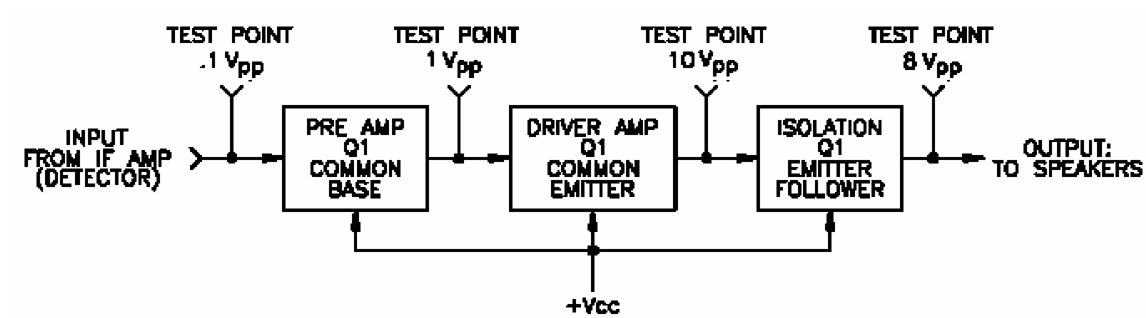


Figure 2. Audio Amplifier Block Diagram

The output from the common base circuit is applied to the common emitter circuit. The common emitter functions as a driver amplifier. As the transistor is a driver amplifier, it has a high power gain and a medium voltage and current gain. Because the transistor is a common emitter configuration, the output waveform is 180o out of phase with the input signal. The output from the transistor is applied to the emitter follower. The purpose of the emitter follower is to isolate the audio amplifier from the rest of the radio and to provide impedance matching. To do so, it has high input impedance and low output impedance. The emitter follower configuration has a low voltage gain and a high current gain. This means that if a 1 volt signal is applied to its base, a signal less than 1 volt will appear on its emitter.

Voltage gain

Voltage gain is calculated by dividing the voltage out of the circuitry by the voltage into a circuit. If the circuit has two resistors on the input, measure the voltage between the two resistors and call that voltage E_{IN}.

$$A_V = \frac{E_{OUT}}{E_{IN}}$$

If the circuit has 0.1 volts input and 100 volts output, substitute the known values into the formula:

$$A_V = \frac{E_{OUT}}{E_{IN}} = \frac{100\text{ V}}{0.1\text{ V}} = 1000$$

Total voltage gain for all the stages can be calculated by two different methods. The first one is to multiply together the individual gains of all the stages.

$$A_{VT} = A_{V1} \times A_{V2} \times A_{V3} \times A_{V4}$$

If the amplifier has four stages with gains of 5, 10, 0.9 and 0.6, what is the total gain?

First, write the formula:	$A_{VT} = A_{V1} \times A_{V2} \times A_{V3} \times A_{V4}$
Substitute known values:	$A_{VT} = 5 \times 10 \times 0.9 \times 0.6$
Multiply:	$A_{VT} = 27$

The second method is to divide the total output voltage of the final stage by the input voltage of the first stage.

$$A_{VT} = \frac{E_{OUT}\text{ (last stage)}}{E_{IN}\text{ (first stage)}}$$

For an amplifier section that has an input voltage of 10 mV and an output voltage of 15 volts, it only takes a few steps to calculate total voltage gain.

First, write the formula:	$A_{VT} = E_{OUT}\text{ (last stage)}/E_{IN}\text{ (first stage)}$
Substitute known values:	$A_{VT} = 15\text{ V}/10\text{ mV}$
Divide:	$A_{VT} = 1500$

Either method takes into consideration the fact that some voltages will have less unity gain (less than 1) or possibly a very high gain.

Current

Input and output currents are as easy to calculate as voltage gain. You will cover input current first. Remember, on the input of the first stage there is a resistor biasing network. The voltage out of the network is less than the voltage applied to the network. Figure 3 illustrates where to take the voltage checks. The way to calculate input current is to subtract the voltage into the stage by the voltage applied to the base of the transistor, and then divide that figure by the input resistance.

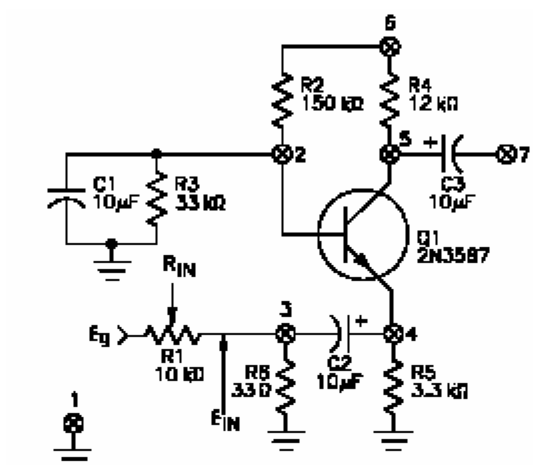


Figure 3. Test Points for Eg and EIN

If an amplifier has 5 volts applied to it from a generator Eg, 0.5 V are applied to the base, and the input resistor has a resistance of 5 kilo-ohms, what is the current into the amplifier?

First, write the formula:	$I_{INPUT} = \dfrac{E_g - E_{IN}}{R_{IN}}$
Substitute known values:	$I_{INPUT} = \dfrac{5\ V\ -\ 0.5\ V}{5\ k\Omega}$
Subtract the voltages:	$I_{INPUT} = \dfrac{4.5\ V}{5\ k\Omega}$
Divide:	$I_{INPUT} = 9\ mA$

Output current is just as easy to calculate. Figure 6 illustrates an output circuit. To determine the output current, just divide the output voltage by the load resistance.

$$I_{OUTPUT} = \frac{E_{OUT}}{\text{load resistance}}$$

If a circuit has an output voltage of 0.75 volts and the load has a resistance of 15 ohms, what is the output current?

First, write the formula:	$I_{OUTPUT} = \dfrac{E_{OUT}}{\text{load resistance}}$
Substitute known values:	$I_{OUTPUT} = \dfrac{75\ V}{15\ \Omega}$
Divide:	$I_{OUTPUT} = 50\ mA$

Power

The final circuit calculations are input and output power. You will start with input power. The formula for input power is to multiply the input current by the input voltage. If a circuit has an input current of 25mA and a voltage input of 0.4 volts, what is the power into the circuit?

First, write the formula:	$P_{IN} = I_{IN} \times E_{IN}$
Substitute known values:	$P_{IN} = 25\ mA \times 0.4\ volts$
Multiply:	$P_{IN} = 10\ mW$

Output power is just as easy to calculate. Multiply the output voltage by the output current. That gives the power supplied to the load. If a circuit has an output voltage of 0.3 volts and an output current of 10mA, what is the power out?

First, write the formula:	$P_{OUT} = I_{OUT} \times E_{OUT}$
Substitute known values:	$P_{OUT} = 10\ mA \times 0.3\ volts$
Multiply:	$P_{OUT} = 3\ mW$

EXPERIMENT

In this experiment, you will investigate how a three stage audio amplifier operates. You will measure PC130-30A, PC130-31, and PC130-32 circuit voltages and calculate circuit current and voltages.

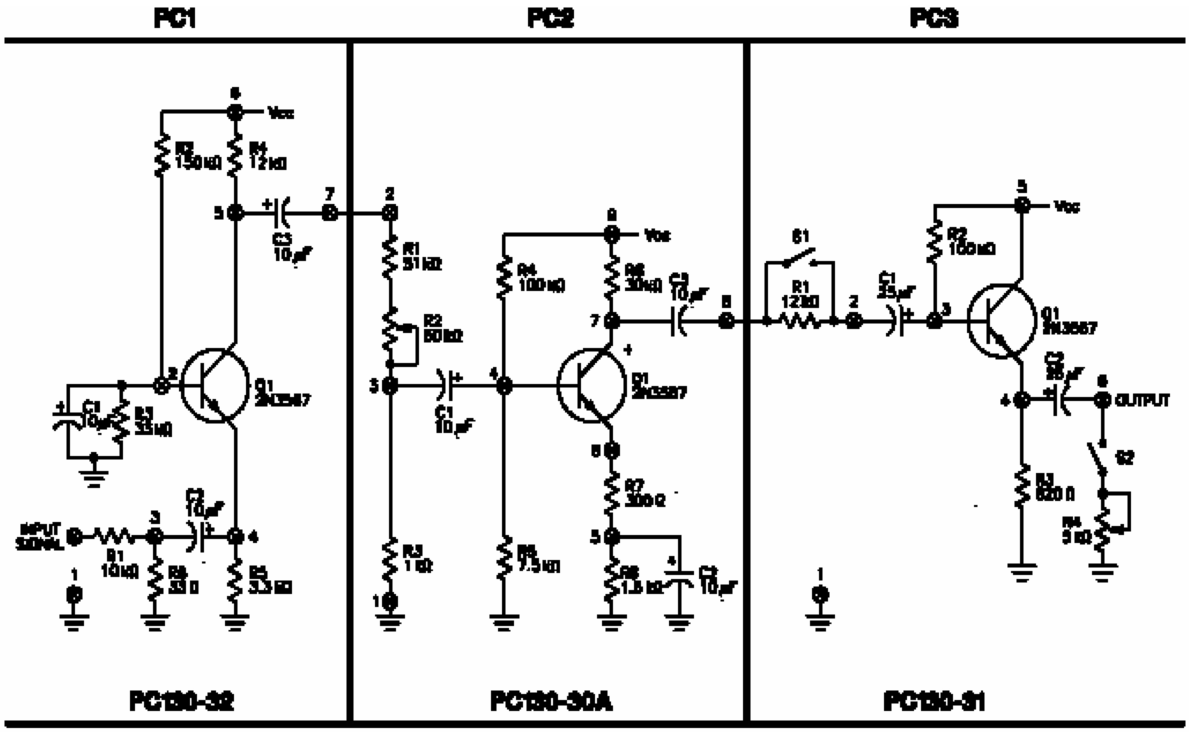


Figure 4. Three Stage Audio Amplifier

PROCEDURE

1. Set both SUPPLY controls to OFF, and turn the console POWER switch to ON. Insert the following cards in the indicated PC connectors:

   PC130-32 . . . . PC1
   PC130-30A PC2
   PC130-31 . . . . PC3

2. Connect the function generator to the console PC1 INPUT BNC. Set the SPKR switch to ON. Set the PC130-31 switches S1 and S2 to OUT. Set PC130-30A R2 fully CW.

Procedure Steps 1 and 2 establish the block diagram of Figure 5. Notice that R1 of PC130-32 is considered external to the common base amplifier and is used to determine I_{IN} of the block.

3. Set the console POSITIVE SUPPLY control to 12 volts and set the PC1, PC2, and PC3 DC POWER switches to ON.
4. Set the function generator to SINE WAVE at 1 kHz. Connect the oscilloscope input to the SPKR output (PC130-31 TP6 to TP1) and adjust the function generator amplitude until EOUT = 0.2 VPP. You should hear a 1 kHz tone from the speaker.
5. Measure the AC peak voltages indicated in Figure 5 and record the results in the appropriate blanks. HINT: Use the + supply negative lead for ground.
6. Based on the voltages measured in Step 5, the remaining data required for the block diagram may be computed. Determine A_{V1}, A_{V2}, A_{V3}, and A_{VT} for Figure 5 and record the results in the appropriate blanks.

$$A_{V1} = \frac{E_{OUT1}}{E_{IN1}} \qquad A_{V2} = \frac{E_{OUT2}}{E_{OUT1}} \qquad A_{V3} = \frac{E_{OUT3}}{E_{OUT2}}$$

$$A_{VT} = \frac{E_{OUT3}}{E_{IN1}} \quad \text{or} \quad = A_{V1} \times A_{V2} \times A_{V3}$$

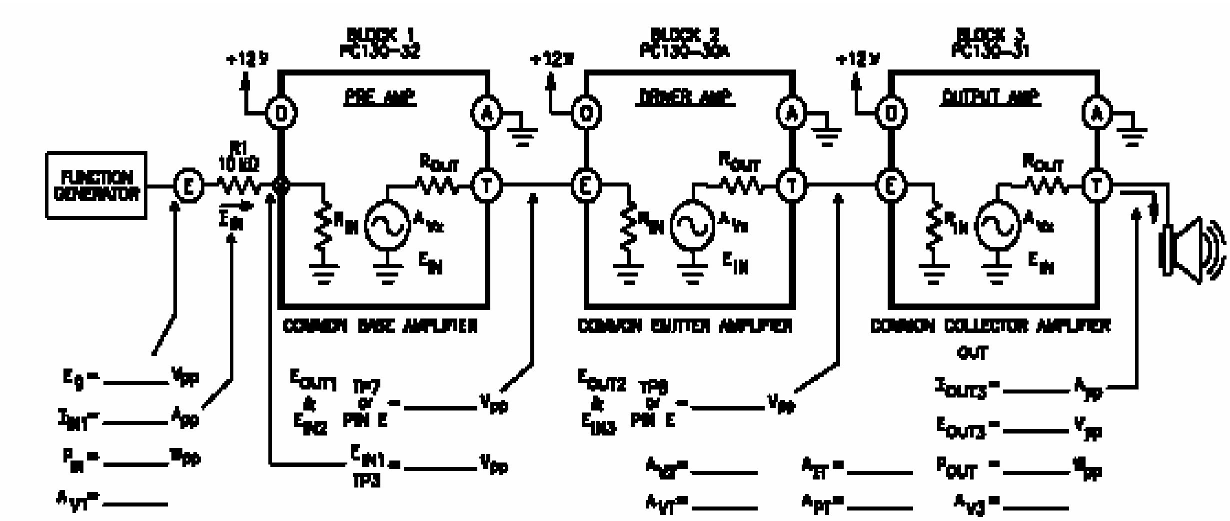


Figure 5. Block Diagram and General Information for PC130-32, PC130-30A, PC130-31 Cascade Amplifier System

7. Determine I_{IN} and P_{IN} to the first block of Figure 5 and record the results in the appropriate blanks.
8. Determine I_{OUT3} and P_{OUT} of the last block of Figure 5 and record the results in the appropriate blanks.

$$I_{OUT3} = \frac{E_{OUT3}}{50\ \Omega\ \text{(SPEAKER)}}$$

$$P_{OUT} = E_{OUT3} \times I_{OUT3} \quad \text{(POWER INTO THE SPEAKER)}$$

9. Determine A_I(TOTAL) and A_P(TOTAL) for Figure 5. Record the results in the appropriate blanks.

$$A_{IT} = \frac{I_{OUT3}}{I_{IN1}}$$

Notice that the actual circuits were not used, only the block diagram. You measured the input/output voltages of each stage and then calculated the other values to determine normal operation.

10. Amplifiers are loaded down by the stage connected to each output. A common fault which is easy to observe at the block level happens when the wire connecting the output of one block to the input of the next block is open. This removes the load effect on the output of the amplifier preceding the open and its output increases noticeably (its A_V increases). Transfer the values of Figure 5 for E_{OUT1} through E_{OUT3} to the NORMAL column of Table 1.
11. Turn the console POWER switch to OFF and remove PC130-30A from the PC2 connectors. Turn the console POWER switch to ON and measure E_{OUT}. Record the results in the OPEN E_{IN2} column of Table 1.
12. Turn the console POWER switch to OFF, and install PC130-30A into the PC2 connectors. 13. Repeat Steps 11 and 12 for PC130-31. Record the results in the OPEN EIN3 column of Table 1.
14. Set the SPKR switch to OFF, and return the console POWER switch to ON. Measure E_{OUT1} through E_{OUT3} and record the results in the OPEN LOAD column of Table 1.

    Set the SPKR switch to ON at the completion of this step.

Table 1. Effects of Open Load on Each Block of a Three Stage Amplifier

CONDITION	NORMAL	OPEN E_{IN2}	OPEN E_{IN3}	OPEN LOAD
E_{OUT1} (TP7)				
E_{OUT2} (TP8)				
E_{OUT3} (TP6)				

Notice that E_{OUT} is higher when there is no load connected to the output.

15. Return both SUPPLY controls to OFF, turn the console POWER switch to OFF, and return all equipment to its designated storage area.

CONCLUSIONS

What did you learn about audio amplifiers in this part of the experiment? Answer the following questions by writing the answers in the blank spaces.

1. Did the three stage amplifier increase the amplitude of E_{IN}? YES ________ NO ________
2. Which circuit board exhibited phase inversion? ____________________
3. Why does the circuit board exhibit phase inversion?

____

SUMMARY

- A block diagram portrays individual stages or functions as blocks.
  – A block will contain the name of the circuit.
  – Input and output waveforms and voltage values will be given.
- A block diagram is a troubleshooting aid that breaks major circuits down into smaller diagrams for signal tracing.
- **Outside – In** is a method of looking at equipment for troubleshooting or educational purposes.
- Voltage gain of a stage is calculated by using the formula:

$$A_V = \frac{E_{OUT}}{E_{IN}}$$

- Total voltage gain of an amplifier section is calculated by using the formula

$$A_{VT} = A_{V1} \times A_{V2} \times A_{V3} \times \ldots\text{etc.}$$

- Input current is calculated with the formula:

$$I_{INPUT} = \frac{E_g - E_{IN}}{R_{IN}}$$

- Output current is calculated by dividing the output voltage by the load resistance.
- Input power is calculated by multiplying the input current by the input voltage.
- Output power is calculated by multiplying the output current by the output voltage.

EXERCISES

______ 1. Which diagram shows all the components and connections in a piece of electronic equipment?

a. Functional block diagram
b. Block diagram
c. Schematic diagram
d. Troubleshooting diagram

______ 2. How does a block diagram make signal tracing easier?

a. Shows all components and connections
b. Shows just test points and signal flow
c. Has the signal path marked through the components
d. Lists all possible failures and waveforms

______ 3. If an amplifier has an input voltage of 6 mV and an output of 12 volts, what is the total gain of the amplifier?

a. 2000
b. 200
c. 20
d. 2

______ 4. If an amplifier section consists of three stages with gains of 15, 8, and 0.5, what is the total voltage gain of the amplifier?

a. 60
b. 600
c. 6
d. 80

______ 5. If an amplifier section consists of six stages with gains of 5, 8, 2, 5, 6, and 0.5, what is the total voltage gain of the amplifier?

a. 12
b. 120
c. 1200
d. 1.2

______ 6. If a circuit has an E_g of 40 volts, an E_{IN} of 10 volts, and an input resistance of 100 kΩ, what is the input current of the circuit?

a. 0.3 microamps
b. 3 microamps
c. 30 microamps
d. 300 microamps

______ 7. If an amplifier has a voltage output of 0.8 volts and a load resistance of 400 ohms, what is the output current of the amplifier?

a. 2 amps
b. 0.2 amps
c. 2 milliamps
d. 20 milliamps

______ 8. If a circuit has an input current of 20 mA and a voltage input of 1 volt, what is the input power?

a. 20 mW
b. 2 mW
c. 200 mW
d. 2 watts

______ 9. If a circuit has an output current of 5 mA and a voltage output of 0.1 volt, what is the output power?

a. 500 mW
b. 50 mW
c. 5 mW
d. 0.5 mW

______ 10. If a circuit has an output current of 0.2 mA and an output power of 1 mW, what is the voltage out?

a. 0.005
b. 0.05
c. 0.5
d. 5

Lab Session 05

OBJECTIVES

- Identify push-pull amplifier schematic symbols.
- Describe operating characteristics of a push-pull amplifier.
- Observe normal operation and troubleshoot a push-pull amplifier circuit

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card: PC130-34
- Function Generator
- Oscilloscope
- Multimeter

INTRODUCTION

In previous experiments, you have used common emitter and common collector amplifiers to drive loads simulated by small resistances and speakers. With real equipment, that would not have been done. Amplifiers such as the common emitter and collector configurations are suitable for high resistance loads. Many applications, such as the output stages of audio amplifiers, require a different type of amplifier. That type of amplifier is the push-pull amplifier.

Push-Pull Amplifier

The push-pull amplifier is also called the complementary symmetry amplifier. Figure 1 illustrates a typical push-pull configuration. Your question right now is, "Why do we need another type of amplifier?" The answer: Efficiency is an important consideration in electronics.

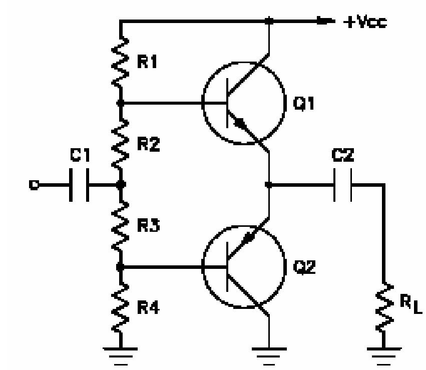


Figure 1. Typical Push-Pull Amplifier

The closer the output resistance of an amplifier is to load resistance, the more power is transferred to the load. A problem with the common emitter and common base configurations is that they have a fairly high output resistance. Many electronic loads, such as audio speakers, have a low resistance or impedance. If the amplifier is to output the maximum power to a low resistance load, then the output resistance of the amplifier must be low. That is why the push-pull amplifier was developed. The push-pull amplifier has virtually no output resistance. Therefore, in a circuit with one power supply and ground, the output of the amplifier can be between V_{CC} and ground. Figure 2 illustrates the two major variations of the push-pull amplifier. The configuration in Figure 2A consists of two transistors, one PNP and one NPN, connected between V_{CC} and ground. Figure 2B has a transformer input and output. The transformers are added to impedance match the input and output of the push-pull amplifier with the preceding stage and the load.

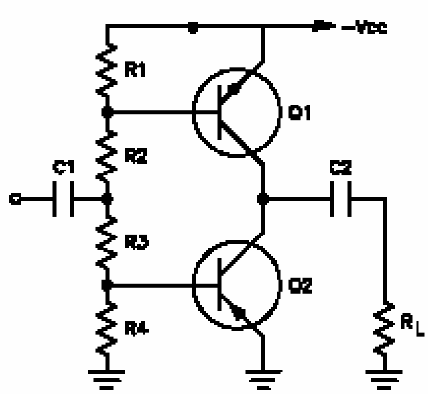


Figure 2A. Push-Pull Amplifier

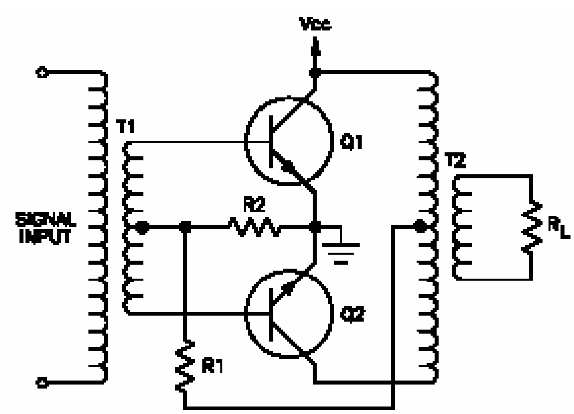


Figure 2B. Push-Pull Amplifier

As an example, if V_{CC} is 12 volts, the design allows for a considerable voltage swing. With that voltage swing applied over a low resistance load such as a speaker, the power output can be high. In the typical car AM/FM radio, the usefulness of the push-pull amplifier becomes apparent. V_{CC} in a car radio is 12 volts and the impedance of a speaker may be as low as 4 ohms. The maximum output voltage of the radio's push-pull amplifier to the speaker would be 12 volts. Converting the peak 12 volts to RMS would yield an RMS voltage of 4.24 volts. The average power to the speaker would equal the output voltage squared divided by the impedance of the speaker of 4.5 watts average. As can be seen from Figure 2, a push-pull amplifier is actually two amplifiers connected in series, with the load parallel to their output. Push-pull amplifiers can be either the common emitter or common base configurations. If the circuit uses common emitter amplifiers, the collectors are tied together and the load is connected to the junction of the collectors. If the circuit uses common collector amplifiers, the emitters are tied together and the load is connected to the junction of the emitters. You will find that most push-pull amplifiers are of the common collector configuration, due to the superior characteristics and stability of that configuration.

The common collector push-pull amplifier is also called the complementary symmetry amplifier. That is because the two output transistors are of complementary materials: NPN and PNP. The term symmetry is derived from the fact that each half of the amplifier is the mirror image of the other half. The term push-pull describes actual circuit operation, as one output transistor pushes current through the load to generate the negative alternation and the other transistor pulls the current through to generate the positive alternation of the output.

The bias of push-pull amplifiers is unique among amplifier configurations. Normally, they are biased at or near cut-off. In a one transistor configuration, that would give a distorted output. However, since two transistors are used, each furnishing one half of the output, the resulting amplification is undistorted, efficient, and high powered.

EXPERIMENT

Figure 3 illustrates a typical push-pull amplifier circuit. You will notice that it is a complementary symmetry configuration. The clue to that observation is the fact that one transistor is an NPN and the other is a PNP. C1 is a coupling capacitor that will pass the AC variations and block all DC voltages from the previous stage. R1, R2, R3, and R4 form a voltage divider network that provides the proper base bias to both of the transistors. Q1 amplifies the positive alternation and Q2 amplifies the negative alternation. When the input waveform goes positive, it will increase the forward bias on Q1 and decrease the bias on Q2. When the signal goes negative, it will increase the bias on Q2 and decrease the bias on Q1. As you can see, the transistors lend themselves quite well to this type of amplification.

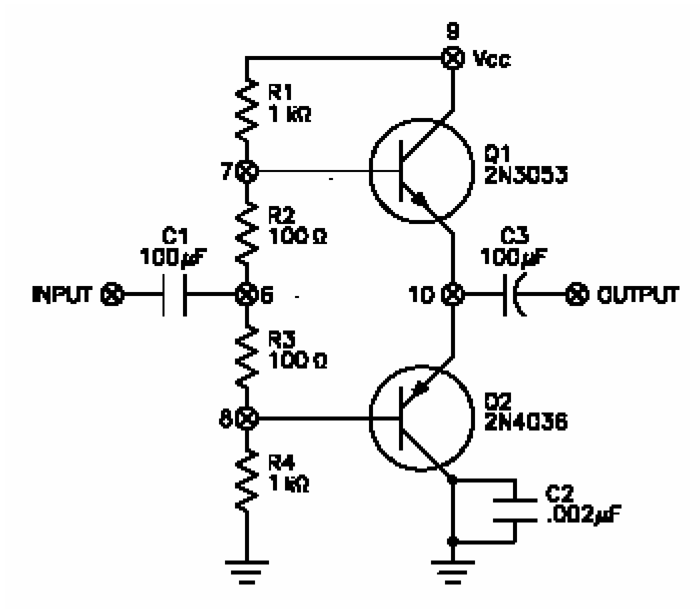


Figure 3. Push-pull Amplifier

Preparation

Examine the PC130-34 experiment card and its schematic in Figure 4. Notice that it is a typical push-pull amplifier circuit. The purpose of the Q1 stage is to deliver enough power to drive both Q2 and Q3. Notice that Q1 is nothing more than a normal common emitter amplifier.

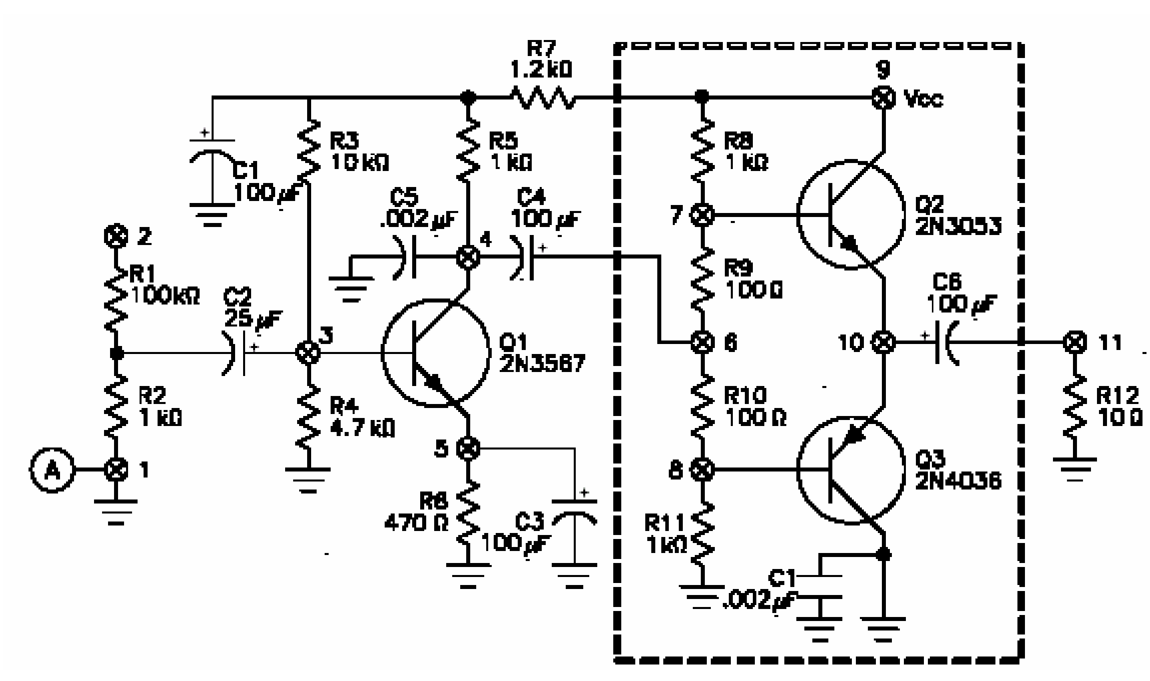


Figure 4. PC130-34 Schematic

1. What type of transistor is Q2? ______________________
2. What type of transistor is Q3? ______________________
3. What configuration are the transistor amplifiers? ______________________

PROCEDURE

1. Set the POSITIVE and NEGATIVE SUPPLY controls to OFF and turn the console POWER switch to ON. Insert PC130-34 into the PC3 connector. Connect the function generator output to the console PC2 OUTPUT BNC. Set the function generator to SINE WAVE at 1 kHz. Do not apply power to the function generator at this time.
2. Set the test console POSITIVE SUPPLY control to +15 volts and set the PC3 DC POWER switch to ON to establish the circuit of Figure 4.
3. Measure the DC bias voltages indicated in Figure 5, using an external voltmeter. You are measuring the normal DC bias voltages in the circuit.
4. Set the function generator to ON. Adjust the function generator output until EOUT (TP11) indicates 0.6 V_{PP} as measured with the oscilloscope. Measure EIN of the push-pull stage (TP6) and record the results below. **Make sure the SPKR switch is set to OFF.**

   E_{IN} Push-Pull = ______________

5. Determine AV of the push-pull stage and record below.

   $A_{VPush\text{-}Pull} = E_{OUT} \div E_{IN} = 0.6\ V_{PP} \div E_{IN} =$ ______________

   Measure EIN to the driver stage (TP3) and record below.

   E_{IN} Driver = ______________

6. Determine AV of the driver stage and record below.

   $A_{V(driver)} = E_{IN}$ Push-Pull $\div$ E_{IN} driver = ______________

Notice that the driver amplifier, Q1, has a large AV. This boosts the signal level up. Q2 and Q3 amplify the current supplied to the output; their AV is low, but Q1, Q2, and Q3 working together supply high voltage and current gain.

Now, let's measure the AC waveforms throughout the circuit.

7. Connecting the oscilloscope across TP2, record the waveform. This is the input to the circuit.

8. Connecting the oscilloscope across TP3, record the waveform. This is the input signal to the base of Q1.
9. Connecting the oscilloscope across TP4, record the waveform. This is the Q1 collector waveform. Notice the amplification of the input signal.
10. Connecting the oscilloscope across TP6, record the waveform. This is the input signal to Q2 and Q3.
11. Connecting the oscilloscope across TP7, measure the voltage and note the slight voltage drop due to the 100 ohm resistor (R9). This is the input to Q2.
12. Connecting the oscilloscope across TP8, measure the voltage and note the slight voltage drop due to the 100 ohm resistor (R10). This is the input to Q3.
13. Connecting the oscilloscope across TP10, record the waveform. This is the output of the push-pull amplifier.
14. Unless you are going on to Part 2 of this experiment, return the POSITIVE and NEGATIVE SUPPLY Controls to OFF and turn the console POWER switch to OFF.

Return all equipment to its designated storage area.

CONCLUSION

1. Did the push-pull amplifier amplify both alternations of the input signal? YES ________ NO ________
2. Was the amplified waveform distorted? YES ________ NO ________
3. What was the approximate gain of the push-pull amplifier? (TP10 waveform divided by TP3 waveform) ________________________
4. Was there phase inversion with the push-pull amplifier? YES ________ NO ________

Push-pull amplifiers provide a high gain with little or no distortion.

SUMMARY

- The push-pull amplifier:
  – Has a very low output impedance.
  – Is ideally suited for low resistance loads.
- The push-pull amplifier overcomes the high output impedance of the common base and common emitter transistor amplifier configurations.
- The transistors of a push-pull amplifier are connected in series, and their output is in parallel with the load.
- If the push-pull uses common emitter amplifiers, the collectors are tied together.

- If the push-pull uses common collector amplifiers, the emitters are tied together.
- The most common push-pull amplifier configuration is the common collector, due to superior stability and other characteristics.
- Push-pull amplifiers are biased at or near cut-off.
- The push-pull amplifier requires the operation of both transistors to amplify the entire waveform. One transistor pushes the current through the load to develop the negative alternation, and the other pulls the current through to develop the positive alternation.
- A push-pull amplifier is also called a complementary symmetry amplifier.

EXERCISES

________ 1. What is another name for a push-pull amplifier?

a. Symmetry complementary amplifier
b. Symmetry amplifier
c. Complementary symmetry amplifier
d. Complementary amplifier

________ 2. What is the main advantage of a push-pull amplifier?

a. Efficiency
b. High power gain
c. Simple design
d. High current

________ 3. What is the output resistance of a push-pull amplifier?

a. High
b. Medium
c. Variable
d. Low

________ 4. The push-pull amplifier is ideally suited to drive what type of loads?

a. Low resistance
b. Low power
c. High resistance
d. High power

________ 5. When does the maximum amount of power transfer from an amplifier to the load occur?

a. When the output resistance of the amplifier is less than the resistance of the load
b. When the output resistance of the amplifier is greater than the resistance of the load
c. When the output resistance of the amplifier equals the load resistance
d. When two driver transistors are used

________ 6. A push-pull amplifier can be described as two transistors connected in ____________________ .

a. series
b. tandem
c. parallel
d. opposition

________ 7. The output of a push-pull amplifier is in ____________ with the load.

a. series
b. tandem
c. parallel
d. opposition

________ 8. Why was the push-pull amplifier given its name?

a. Because the transistor first pushes the voltage through the load, then pulls it through
b. Because the transistor first pushes the voltage through the load to develop the positive alternation, and then the other transistors pulls the voltage through the load to develop the negative alternation
c. Because the transistor first pushes the current through the load and then pulls it through
d. Because the positive alternation is developed by one transistor pushing current through the load and the negative alternation is developed by the other transistor pulling the current through the load

________ 9. How are push-pull amplifiers normally biased?

a. Maximum conduction
b. Midway between saturation and cut-off
c. At or near cut-off
d. At saturation

________10. What is the most common push-pull amplifier configuration?

a. Common base
b. Common collector
c. Common emitter
d. Common gate

Section Two

Oscillators

Lab Session 06

OBJECTIVES

1. Describe the different classes of amplifier operation.
2. Identify the circuitry for a series-fed and a shunt-fed Hartley oscillator.
3. Identify the requirements to sustain oscillations at a given frequency in the Hartley oscillator.
4. Describe the operating characteristics of the series-fed and shunt-fed Hartley oscillator.
5. Observe normal operation and troubleshoot a Hartley oscillator circuit.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-35
- Oscilloscope
- Multimeter
- Frequency Counter or equivalent (OPTIONAL)

OVERVIEW

In this lesson, the students are introduced to oscillators, specifically the Hartley oscillator. In communication applications, the common method of transmitting the intelligence from one point to another is by using radio frequency carrier signals. The intelligence is superimposed on the carrier wave and transmitted through space by electromagnetic radiation. This principle is utilized in all types of communications, including radio, television, and radar. At the receiving point, another radio signal must be generated in order to process the received signal and extract the intelligence. The circuit that is normally designed to provide the basic frequency for the carrier of the intelligence and detect this signal at the receiver is the oscillator. It is normally referred to as the **local oscillator**.

INTRODUCTION

In order to build a sinusoidal oscillator, all that is required is an amplifier with a positive feedback. The idea is to use the feedback signal in place of the input signal. Provided that the loop gain and phase are correct, there will be an output signal even though there is no external input. In other words, an oscillator is an amplifier that has been modified by positive feedback to supply its own signal input. In general, oscillators are divided into three main classes: the LC class, the RC class, and the quartz crystal class. There are many variations of these classes, such as the Hartley oscillator, the Colpitts oscillator, the

RC phase shift oscillator (which can be designed with a positive or a negative feedback), the Armstrong oscillator, and the Clapp oscillator. There are variations also of the crystal oscillator reflecting either the LC class or the RC class. Generally, oscillators using an LC resonant circuit provide a practical and economical method of generating the desired radio frequency signal for communication applications. Other methods are utilized for generating high frequency signals, but the operating principles are similar. The Hartley oscillator is commonly found in transmitting and receiving systems.

Basic Sine Wave Oscillator

An oscillator is a device that changes DC energy into AC energy. A resonant circuit consisting of an inductor and a capacitor connected in parallel provides the simplest form of an electrical circuit to provide oscillations. Figure 1(A) illustrates such a circuit. Current will oscillate in a resonant circuit until oscillations are damped out by the resistance of the circuit or by the demand placed upon the load. Figure 1(B) illustrates this relationship.

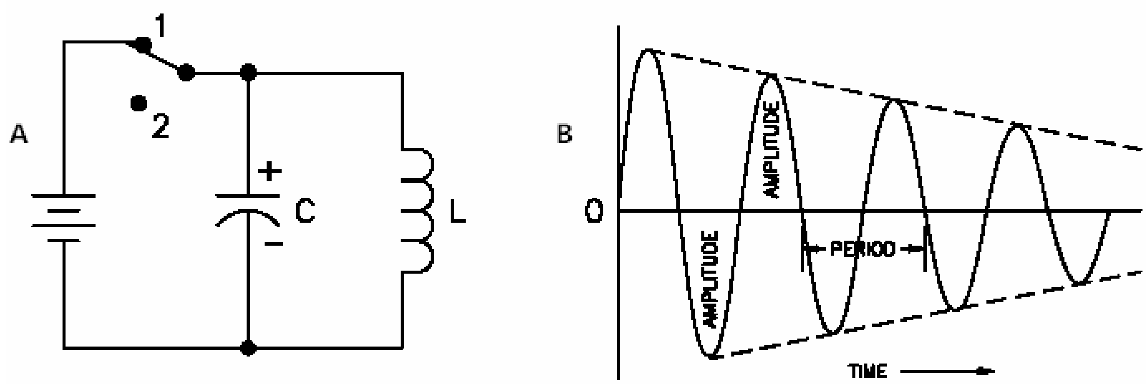


Figure 1. Resonant Circuit and Damped Oscillations

To understand this action, let's assume that the capacitor charges to the polarity shown. When the switch is rotated to position 2, the energy stored in the electrostatic field of the capacitor will be transferred to the magnetic field of the inductor (L) when the capacitor discharges through the inductor. Once the capacitor has discharged, the magnetic field built up in the inductor begins to collapse. The induced voltage in the inductor tends to keep the current flowing in the same direction, transferring the energy stored in the magnetic field of the inductor back into the electrostatic field of the capacitor. The capacitor is then charged in the opposite polarity. The discharge of the capacitor again transfers the energy to the magnetic field of the inductor, and when the magnetic field collapses again, the energy is returned to the capacitor, recharging the capacitor to the initial polarity and completing one cycle. The sequence of storing energy alternately in the electrostatic field of the capacitor and the magnetic field of the inductor results in an alternating motion of current, or an oscillating current. This action continues until the oscillations are damped out by the resistance in the conductor. The process is known as the **flywheel effect**. To keep the oscillations going, energy, in the form of feedback, must be added. The frequency of oscillations is determined by the values of the inductor and capacitor. The resonant frequency of the LC circuit will occur when the energy stored by each component is equal.

The Transistor Amplifier as an Oscillator

A transistor amplifier is an oscillator in which a small amount of the output voltage or current is fed back as an input to the base circuit. The oscillator produces an alternating output voltage, while the only input from an external source is the DC power supplied to the circuit. In the common emitter amplifier, the signal on the collector is of opposite polarity to the original signal on the base; therefore, the feedback signal voltage must be reversed before being applied to the base. Figure 2A is a conventional common emitter amplifier using an NPN transistor. With an external AC signal applied to the base, the transistor produces an amplified output voltage on the collector of opposite polarity to the voltage on the base. If a small amount of the amplified output voltage is fed back directly to the base circuit, as illustrated by the dotted line in Figure 2A, it will have the wrong polarity. The feedback signal will tend to cancel the input on the base of the amplifier, thus decreasing the signal output. This type of feedback is known as **degenerative** or **negative feedback**. If a circuit were designed to pass a signal from the collector to the base and at the same time invert the signal, the amplifier would continue to produce an AC output without an AC input from another source. This type of feedback from collector to base is called **regenerative** or **positive feedback**.

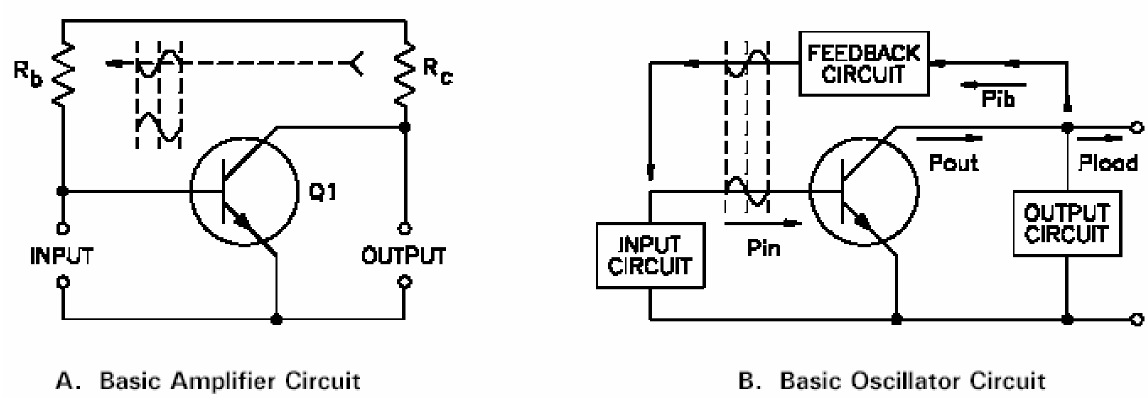


Figure 2. Basic Amplifier Oscillator Circuits

Figure 2B illustrates the diagram of a basic oscillator circuit with the feedback circuit represented as a block diagram. The requirements for an amplifier to function as an oscillator are amplification, regenerative feedback, and a frequency determining circuit.

The Series-Fed Hartley Oscillator

Figure 3 illustrates the schematic diagram of a series-fed Hartley oscillator using an NPN transistor.

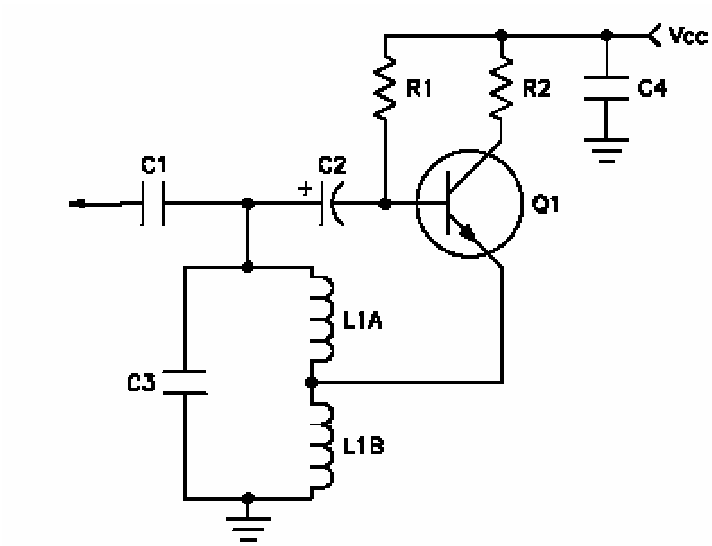


Figure 3. Series-Fed Hartley Oscillator

1. In the study of resonant circuits, you learned that current will oscillate in this type of circuit. The oscillation in the resonant circuit of the series-fed Hartley oscillator causes the potential on the base of the transistor to vary continuously.
2. When DC voltage is applied to the circuit of Figure 3, Q1 is forward biased through R1. Current flows through L1B, Q1, R2, and the power supply source. The voltage drop across L1B causes the junction of L1B-L1A to become positive, which in turn causes the top of L1A and C3 to become positive. The positive going change is coupled through C2 to the base. This regenerative voltage feedback causes current to continue to increase, which provides more regenerative feedback. As C2 couples the positive change to the base, the base draws more current and charges C2 with a surplus of electrons on the base side. This is called base leak bias.
3. Regenerative action continues until current is maximum. Maximum current is determined by the total opposition in the conduction path. When the current stops increasing, C2 begins to discharge through R1, driving the base in a negative direction. Whether or not Q1 is cut off depends on the amount of regeneration and the charge accumulated by C2. As the current decreases, C3 discharges through L1B and L1A, causing the top of the resonant circuit to begin the negative excursion of the sine wave cycle. The flywheel effect of the resonant circuit causes the top of the circuit to again go positive at the end of the first AC cycle.
4. In the meantime, C2 has been discharging through R1, but the long time constant prevents C2 from losing very much of its charge. As soon as the positive alternation at the top of the resonant circuit exceeds the charge remaining on C2, Q1 is forward biased and Q1 conducts for a short time. This recharges C2 to approximately the peak value of the oscillations.
5. This action continues as long as power is applied and oscillations are sustained. The output signal will be a sine wave of constant amplitude and frequency.
6. Resistor R2 provides a means of observing the collector to determine the class of operation. R2 also serves as a current limiter to prevent excessive current through

Q1, should oscillations cease due to a malfunction. R2 also functions to control the amplitude of oscillations in the circuit. Without R2 in the circuit, collector current would be larger, which would provide a larger regenerative feedback to the resonant circuit.

7. Base leak bias makes the circuit self starting, because when power is first applied, there is no charge on C2. C2 charges to the approximate peak value of the sine wave signal at the top of the resonant circuit. Therefore, the amount of bias developed adjusts itself automatically to the amplitude of the oscillations.
8. The resonant circuit is the oscillator. The transistor serves as an automatic switch to provide regenerative feedback at the proper time.
9. The amount of feedback provided depends on the ratio of L1B to L1A. Decreasing the value of L1B and increasing L1A increases the amount of feedback. Increasing L1B in relation to L1A decreases the amplitude of the oscillations. The ratio of L1B and L1A is derived from the number of turns in each inductor, which, in this case, is usually fixed rather than being adjustable.
10. Only light loads (low current) should be connected to the output of the oscillator. If too much current is drawn from the circuit, the output may become erratic or oscillations may cease.
11. The output frequency of the oscillator can be determined by calculating the resonant frequency of the LC circuit:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Shunt-Fed Hartley Oscillator

Figure 4 illustrates the schematic diagram of a shunt-fed Hartley oscillator. This circuit uses an NPN transistor, but a PNP can just as easily be used if the power supply polarity is reversed. The circuit operation is described as follows:

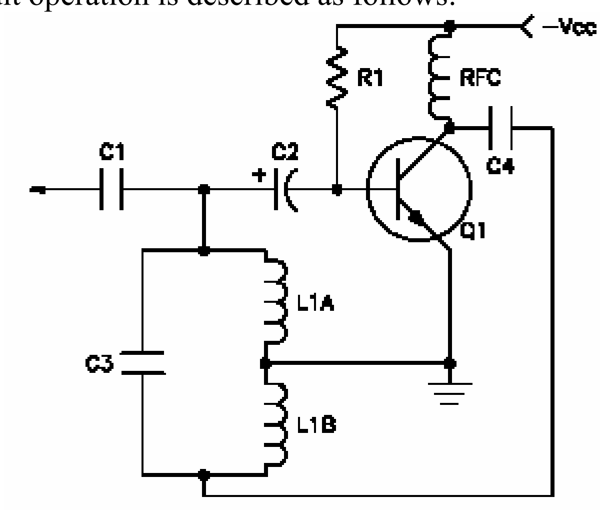


Figure 4. Shunt-Fed Hartley Oscillator

1. Because DC current does not flow through the resonant circuit, you recognize this as a shunt-fed Hartley oscillator.
2. It should be recalled that opposite polarity signals are present at the ends of the

resonant circuit at any instant in time. Therefore, if the top of the resonant circuit is negative, application of a positive voltage to the bottom of the circuit at that instant is regenerative feedback.

3. The following series of events occur with the application of power to the circuit:
    a. Forward bias is provided by R1, and collector current flows. Current through the RFC (radio frequency choke) causes a voltage drop that makes the collector less negative (i.e., positive-going).
    b. The positive-going change is coupled through C4 to the bottom of the resonant circuit. This places energy in the resonant circuit, and the top end of the circuit feels a negative-going change.
    c. The negative change is coupled across C2 as increased forward bias, and current through Q1 increases. The action is regenerative; Q1 current increases to its maximum value.
    d. During this time, electrons are being drawn off the base side of coupling capacitor C2, charging it to a value approximately equal to the peak of the voltage change.
    e. When the current stops increasing, C2 begins to discharge, reducing the bias on Q1. Current decreases and the negative going change is coupled through C4 to the bottom of the resonant circuit. Flywheel action in the circuit is initiated.
    f. A few cycles will be required for oscillations to become maximum and stabilize, but this is completed in a small fraction of a second. Depending upon the amount of feedback, the amount of transistor current, and the charge accumulated on C2, the circuit can operate in any class of operation. Class C operations are the most efficient.
    g. Base leak bias is developed and is self-adjusting to the amplitude of oscillations.
    h. The shunt-fed Hartley oscillator operates much like the series-fed Hartley oscillator. The main difference is in the way regenerative feedback is developed.
    i. In the series-fed oscillator circuit, one end of the resonant circuit is at ground. In the shunt-fed oscillator circuit, AC is present at both ends of the resonant circuit. In some applications, this may be a disadvantage, since capacitance must be detuned by hand during circuit adjustments.
    j. In general, Hartley oscillators can operate over a wide range of frequencies. By making either L or C a variable, the oscillator frequency can be varied over a range of frequencies.

EXPERIMENT

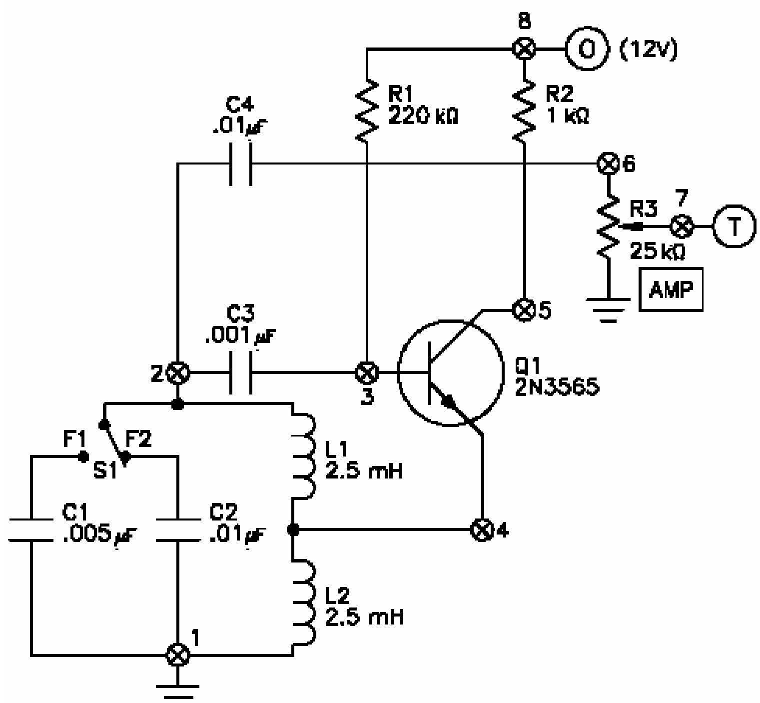


Figure 5. PC130-35 Hartley Oscillator

PREPARATION

Pick up PC130-35 and compare the circuit with the schematic in Figure 5. Switch S1 selects C1 or C2 in parallel to L1 and L2 to determine the frequency of the oscillator.

PROCEDURE

1. Set the POSITIVE and NEGATIVE SUPPLY controls to OFF. Turn the console POWER switch to ON.
2. Install experiment card PC130-35 on the PC1 connector. Set the S1 switch to the F1 position (left) and adjust variable resistor R3 to mid range.
3. Adjust the POSITIVE SUPPLY control for a +12 volt reading.
4. Turn the PC1 DC POWER switch to ON.
5. Perform measurements as indicated to complete Table 1. Set your oscilloscope to the following:

   CH1 VOLT/DIV = 5 V/DIV
   TIME/DIV = 5 µS/DIV
   Input switch = AC

   Adjust the TIME/DIV variable control to display two cycles.

Table 1. Hartley Oscillator Characteristics

OUTPUT WAVEFORM (TP6) ________ V_{PP}	
COLLECTOR WAVEFORM (TP5) ________ V_{PP}	
BASE WAVEFORM (TP3) ________ V_{PP}	
EMITTER WAVEFORM (TP4) ________ V_{PP}	

Notice that the output waveform is a clean sine wave. The collector shows a cut-off of the waveform due to the transistor being biased Class C.

6. Using a multimeter, measure V_{CC} and the bias voltages.

   V_{CC} (TP8) ________ V_C (TP5) ________

   V_B (TP3) ________ V_E (TP4) ________

7. Using the oscilloscope (or frequency counter), measure the output frequency. Connect the oscilloscope to TP6. (Ensure that the TIME/DIV variable control is set to CAL.)

   Measured frequency ________

Using the formula of f_o and Figure 8 with S1 set to F1, calculate the frequency.

Calculated frequency ________

Compare your measured value of frequency to your calculated value. They should be close.

8. On PC130-35, place S1 to the F2 position.
9. Using the oscilloscope (or frequency counter), measure the output frequency. Connect the oscilloscope to TP6. (Ensure that the TIME/DIV variable control is set to CAL.)

Measured frequency ______________________

Using the formula of f_o and Figure 5 with S1 set to F2, calculate the frequency.

Calculated frequency ______________________

Compare your measured and calculated values for the output frequency in Steps 7 and 9. They should be within ±10% of each other. Also notice how changing the value of the capacitor changed the output frequency.

10. This concludes the experiment on the Hartley oscillator. Turn OFF all power. Remove the experiment card PC130-35 from the PC1 connector. Return all equipment to its designated storage area.

SUMMARY

- Oscillator circuits are amplifiers that have the output routed back to the input. No external input is required except for the DC operating voltage.
- To sustain oscillations at a given frequency, the three main requirements of an oscillator is:
  - Amplification
  - Regenerative feedback
  - A resonant circuit
- Hartley oscillators generate a sine wave output and use split inductors.
- The output frequency of the Hartley oscillator can be varied by changing component values in the resonant circuit.
- The power requirements for transistor oscillators are low.
- Either a PNP or NPN transistor can be used in oscillator circuits.
- Oscillators are normally operated Class C for maximum efficiency.
- The series-fed Hartley oscillator has DC current flow through part of the resonant circuit.
- The shunt-fed Hartley oscillator does not have DC current flow in the resonant circuit.
- Base leak bias makes the Hartley oscillator self starting. Base leak bias is self adjusting to the amplitude of oscillations.

EXERCISES

1. An oscillator is a circuit that converts ____________________ .

   a. sine waves to square waves
   b. AC voltages to DC voltages
   c. square waves to sine waves
   d. DC power to AC power

2. Oscillators using resonant circuits normally operate in the _____________ range.

   a. audio frequency
   b. radio frequency
   c. video frequency
   d. radar frequency

3. To insure self starting and self adjustment, RF oscillators normally use a type of bias known as ___________________ .

   a. base leak bias
   b. fixed emitter bias
   c. grounded-base bias
   d. fixed collector bias

4. The most efficient operation of an oscillator is obtained when it is operated Class ____________________ .

   a. A
   b. B
   c. C
   d. AB

5. The series-fed Hartley oscillator __________________ .

   a. has a DC component of current flow through part of the resonant circuit
   b. has only an AC component of current flow through part of the resonant circuit
   c. has a tapped card and a direct emitter
   d. uses tapped capacitance in the resonant circuit

6. Feedback in the series-fed Hartley oscillator is ____________________ .
   a. not used
   b. regenerative
   c. degenerative
   d. Class C

7. For its operation, a transistor oscillator does not need ______________ .
   a. frequency determining circuit
   b. input signal
   c. feedback circuit
   d. DC power

8. If the base coupling capacitor becomes open, ________________ .
   a. the output frequency increases
   b. the transistor cuts off
   c. the transistor conducts DC
   d. the transistor will be damaged

9. The oscillator resonant circuit contains a 0.001 μF capacitor and a 2 mH total inductance. What is the output frequency?

   ____

10. The three requirements for an oscillator to sustain oscillations at a given frequency are:

    1. ________________________

    2. ________________________

    3. ________________________

Lab Session 07

OBJECTIVES

1. Identify the circuitry and schematic diagram for a Colpitts oscillator.
2. Describe the operating characteristics of the Colpitts oscillator.
3. Observe normal operations of Colpitts oscillator.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-36
- Oscilloscope
- Multimeter
- Frequency Counter or equivalent (OPTIONAL)

INTRODUCTION

The Colpitts oscillator is an RF sine wave oscillator that can be used in many applications. As it is required for all oscillators to sustain oscillations at a prescribed frequency, it must incorporate an amplifier, regenerative feedback, and a means of controlling its frequency. Although the Colpitts oscillator is superb at low frequencies, it is not suited for high frequencies (above 1 MHz). The main problem is related to the phase shift through the amplifier. One alternative is an LC oscillator that can be used for frequencies between 1 MHz and 500 MHz. Another alternative is to use a crystal oscillator designed to operate at a low frequency followed by amplifiers and doublers to reach the operating frequency. An amplifier with the correct values of LC in the resonant circuit can feed back a signal with the right amplitude and phase to sustain oscillations. Another factor to consider is that at higher frequencies, the stray capacitance and inductance in the transistor and wiring affect the oscillator's frequency, feedback, output power, and other RF quantities. To correct for this, sometimes the LC circuit is enclosed in an oven where it is kept at a constant temperature. This prevents any changes in the environment from affecting the resonant frequency of the LC circuit.

The Colpitts Oscillator

A basic Colpitts oscillator is illustrated in Figure 1. Although this circuit uses an NPN transistor, a PNP transistor can be used just as easily, with the correct voltage polarity.

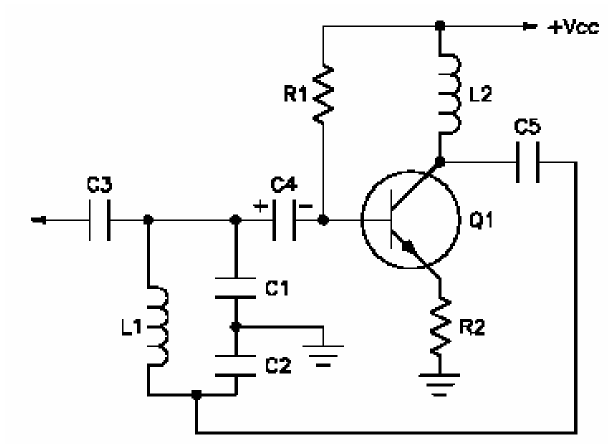


Figure 1. Basic Colpitts Oscillator

Characteristics:

1. The oscillator uses base leak bias to make oscillations self starting. Base leak bias is self adjusting to the amplitude of the oscillations.
2. The resonant circuit uses split capacitance and is an identification feature of the Colpitts oscillator. As was the case for the Hartley oscillator, the resonant frequency of the Colpitts oscillator can be approximated using the formula:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

The total capacitance is equivalent to the capacitance of the tank circuit current. In the Colpitts tank, the circulating current flows through C1, in series with C2. Therefore, the equivalent capacitance is:

$$C = \frac{C1 \times C2}{C1 + C2}$$

3. L2 in the collector circuit develops the feedback signal. Some circuits may use a resistor in place of L2.
4. Resistor R2 in the emitter circuit is a current limiting resistor. If oscillations should cease for any reason, R2 would limit the current to a safe value.
5. The Colpitts oscillator is a shunt type circuit. No DC current flows through the tank circuit. Both ends of the tank circuit have RF signals present.
6. Class C operation is most efficient, but the oscillator can be designed to operate in any class of operation, from A to C.
7. C1 and C2 form an AC voltage divider. The ratio of C2 to C1 determines the amount of feedback voltage applied to the tank. As the value of C2 increases with respect to C1, the feedback is decreased, and vice versa.

Operation:

1. When power is applied, R1 provides forward bias to the base. Current flows through L2, developing a voltage drop that is negative-going at the collector.
2. The negative-going voltage is coupled by C5 to the bottom end of the tank circuit, inserting energy into the tank. Opposite polarity voltages exist across a tank

circuit, so the negative at the bottom end is comparable to a positive change at the top. (It should be recognized that a few cycles will be required for oscillations to build up to full strength.)

3. The positive-going change at the top of the tank is coupled by C4 to the base as regenerative feedback to increase collector current. This action continues until current reaches its maximum value, determined by the opposition in the current path.
4. As C4 couples positive voltage to the base, base current increases and charges C4 to the negative potential on the base side, developing base leak bias.
5. When current stops increasing, C1 and C2 begin discharging and the flywheel effect of the tank current is initiated. At this time, C4 begins to discharge through R1 and reverses the bias on Q1. The collector voltage rises and that change is coupled to the bottom of the tank, aiding the flywheel action.
6. The C4-R1 time constant is long, and C4 only loses a small part of its charge. Note that the charge on C4 determines the class of operation, and the charge on C4 depends on the amplitude of the oscillations. The amplitude of the oscillation depends on the amount of regenerative feedback and the load connected to the oscillator.
7. When the tank oscillation goes positive at the top of the tank on the next cycle and overcomes the charge on C4, Q1's current increases to develop regenerative feedback and oscillations are sustained.
8. The output signal is coupled by C3 to the load. The load current must be small to prevent loading the oscillator. Loading the oscillator may result in erratic operation, changes in frequency, or oscillations that stop altogether.
9. The collector is connected to the opposite end of the tank circuit through C5 and a complete cycle appears at the collector. An output signal could be taken from the collector, but the same load restrictions apply.

Oscillation continues as long as DC power is applied. The Colpitts oscillator can be made tunable over a range of frequencies by making L or C variable. Because the ratio of C1 and C2 controls the amount of feedback and both capacitors would have to be changed proportionately, it is more common to have the capacitance values fixed and vary the inductance of L1. The value of inductance can be changed easily by using a movable core in the coil.

Colpitts Oscillator Using A PNP Transistor

Figure 2 shows the diagram of the Colpitts oscillator using a PNP transistor. Note that the circuit of Figure 2 is identical to Figure 1 except for the transistor and the supply voltage polarity. Either type transistor can be used in the oscillator with no change in overall operation.

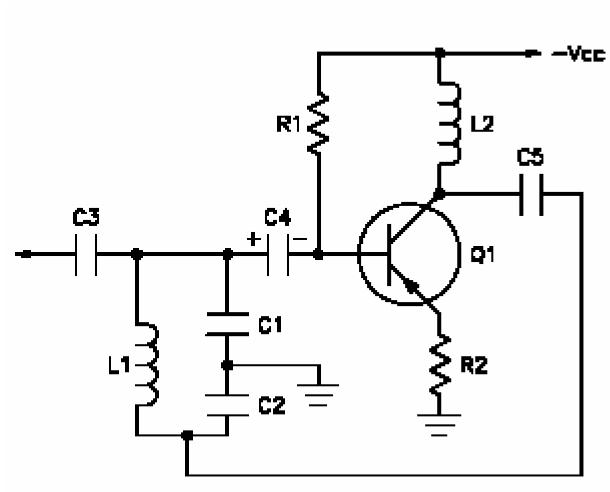


Figure 2. Colpitts Oscillator Using a PNP Transistor

EXPERIMENT

The purpose of this experiment is to illustrate the operating characteristics of the Colpitts oscillator and to demonstrate the effects of bias and frequency changes.

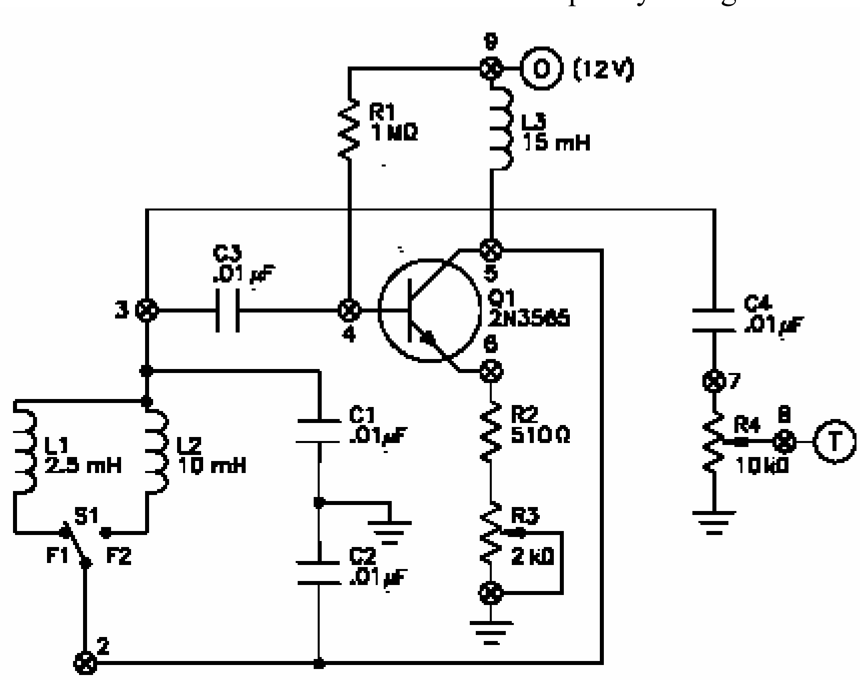


Figure 3. Nida Model PC130-36, Colpitts Oscillator

PROCEDURE

1. Place the POSITIVE and NEGATIVE SUPPLY controls to OFF. Turn the console POWER switch to ON.
2. Refer to Figure 3. Compare this circuit to Figures 1 and 2.

a. What is the purpose of the S1 switch? ____________________

____

b. What is the purpose of R3? ____________________

c. Calculate the output frequency with the S1 switch set to:

F1 __________ F2 __________

d. Why is a feedback capacitor not required? ____________________

____

3. Install PC130-36 on the PC1 connectors, and set switch S1 to the F1 position. Set R4 to the CW position and R3 to the CCW position.
4. Reset the test console.
5. Set the POSITIVE SUPPLY control to a +12 volt reading.
6. Turn the PC1 DC POWER switch to ON.
7. Perform measurements and adjustments to complete all the data required by Table 1.

Set the class of operation by observing the emitter waveform on TP6; adjust R3 for the appropriate waveform in wave shape and amplitude as indicated in the table.

Table 1. Colpitts Oscillator Characteristics

	CLASS A F1	CLASS B F1	CLASS B F2
EMITTER WAVEFORM TP6			
AMPLITUDE	6.0 V_{PP}	5.4 V_{PP}	4.8 V_{PP}
COLLECTOR WAVEFORM TP5			
AMPLITUDE			
PERIOD			
FREQUENCY			

Notice from Table 1 that the collector waveform remains undistorted regardless of the setting of R3 (class of operation). The 51Ω resistor (R2) allows enough resistance to maintain Q1 in the active region regardless of the R3 setting. This guarantees an undistorted collector (output) waveform regardless of the small change in bias. Also notice the calculated resonant frequency (Step 2) is relatively close to the measured resonant frequency. The following steps in the experiment will provide practice in testing, analyzing the schematic, and localizing troubles.

Use Figure 3.

8. Set the oscillator circuit up for F1 Class B as indicated in Table 1. You will only troubleshoot the F1 frequency components.
9. Using a multimeter, measure the DC bias voltages for the normally operating oscillator circuit.

V_B (TP4) = ____________ V_C (TP5) = ____________ V_E (TP6) = ____________

10. This completes the experiment. Reset the test console and turn OFF power to all equipment. Remove PC130-36 from the PC1 connector. Return all equipment to its designated storage area.

SUMMARY

- To sustain oscillations at a specific frequency, the requirements are:
  - Amplification
  - Regenerative feedback
  - A resonant circuit
- Colpitts oscillators generate a sine wave output and use split capacitors.
- The output frequency of the oscillator can be varied by changing the value of the components in the resonant circuit.
- Power requirements are normally low for transistor oscillators.
- Before applying power to any transistor circuit, you must check the power supply voltage and polarity to insure that they are proper for the circuit.
- Either PNP or NPN transistors may be used in oscillator circuits.
- Oscillators are normally operated Class C for best efficiency.

EXERCISES

1. Regenerative feedback is a feedback signal fed back ____________ .
   a. out of phase with V_{CC}
   b. in phase with input signal
   c. in phase pulse with V_{CC}
   d. out of phase with input signal

2. LC type oscillators normally operate in the _________ frequency range.
   a. radar
   b. audio
   c. radio
   d. video

3. The type of bias that is self adjusting and makes an oscillator self-starting is called ______________________ .

4. The Colpitts oscillator will produce an RF output voltage when operating _______________ .
   a. Class A
   b. Class B
   c. Class C
   d. Class A, B, or C

5. The feature of the Colpitts oscillator that makes it easy to recognize is ____ .

6. The Colpitts oscillator is a shunt type of oscillator because ____

7. The oscillator that has the best frequency stability is the ______________ oscillator.
   a. Hartley
   b. Colpitts
   c. crystal
   d. RC phase shift

8. Refer to Figure 5. Which component develops the regenerative feedback?

   ____ .

9. Refer to Figure 4. If C2 is made larger and C1 is made smaller, the feedback will ______________________ (increase)(decrease).

10. Oscillations in a Colpitts oscillator will continue _______________ .
    a. as long as DC power is applied
    b. as long as there is a regenerative feedback
    c. as long as the resonant circuit is tuned
    d. as long as the transistor is conducting

Lab Session 08

OBJECTIVES

1. Identify the circuitry and schematic diagram of an RC phase shift oscillator.
2. Describe the operating characteristics of the RC phase shift oscillator.
3. Observe normal operations of the RC phase shift oscillator.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-37
- Oscilloscope
- Multimeter
- Frequency Counter or equivalent (OPTIONAL)

OVERVIEW

The resistive/capacitive (RC) phase shift oscillator consists of a common emitter amplifier with a regenerative feedback network. A common emitter amplifier has a 180o phase shift from input to output (base to collector). Since the feedback required for an oscillator to sustain oscillation must be in phase or regenerative, compensation must be made for the phase shift of the emitter amplifier. If the signal is taken from the collector and placed through some RC networks, its phase can again be shifted by 180^o and then the signal can be applied to the base of the emitter amplifier in phase. Regardless of the individual R and C values, the overall phase shift must be approximately 180^o for the circuit to oscillate. Normally, there are at least three phase shift networks in the phase shift oscillator. Resistive/capacitive (RC) oscillators use the charge and discharge action of the capacitor across the resistor in the feedback path to sustain oscillations. The RC oscillator is used in audio and low RF frequency ranges. There are two types of RC oscillators, the phase shift oscillator and the Wien-Bridge oscillator.

INTRODUCTION

An oscillator circuit is one which delivers an AC output, normally with a desired waveform and frequency, without the use of an external signal. The operation of an oscillator circuit depends on the special application of the principal amplifier circuit. An oscillator is an amplifier that derives its own output signal. The amplifier illustrated in Figure 1(A) has a gain of 100 and produces an output of 10 volts when a signal of 0.1 volt is applied to its input terminals. Note that the input and output voltages of the amplifier have the same polarity (i.e., they are in phase). In Figure 1(B), the switch contact has been connected to the load resistor. Thus, when the amplifier input switch is moved from position 1 to position 2, the external input voltage in Figure 1 is replaced by its exact duplicate obtained from a tap of the output load resistor of the amplifier. The new input voltage is identical to the original external input signal in both amplitude and phase; therefore, the external input signal is no longer needed, and the amplifier continues to produce an output voltage as long as the feedback path from the output to the input is not removed. Under this condition, the amplifier is said to oscillate.

In practical oscillators, the oscillations are started by variations in collector current as the transistor begins to conduct. Oscillations build up fast because of the feedback path and the amplifying action of the circuit. It is not required to use an external signal source or a switch. These elements are shown in Figure 1 to illustrate the principle. The preceding explanation of the operation of oscillators indicates that an amplifier performs as an oscillator, provided a portion of its amplified output is fed back to the input with the proper amplitude and phase. These are two basic operating requirements of any type of oscillator. The other important consideration is the frequency determining network. In the phase shift oscillator, the requirements for phase shift and amplitude are fulfilled by resistors and capacitors inserted in the feedback circuit of a conventional amplifier. The feedback circuits also determine the operating frequency of the oscillator output. Oscillators of this type are called resistance/capacitance oscillators or simply RC oscillators.

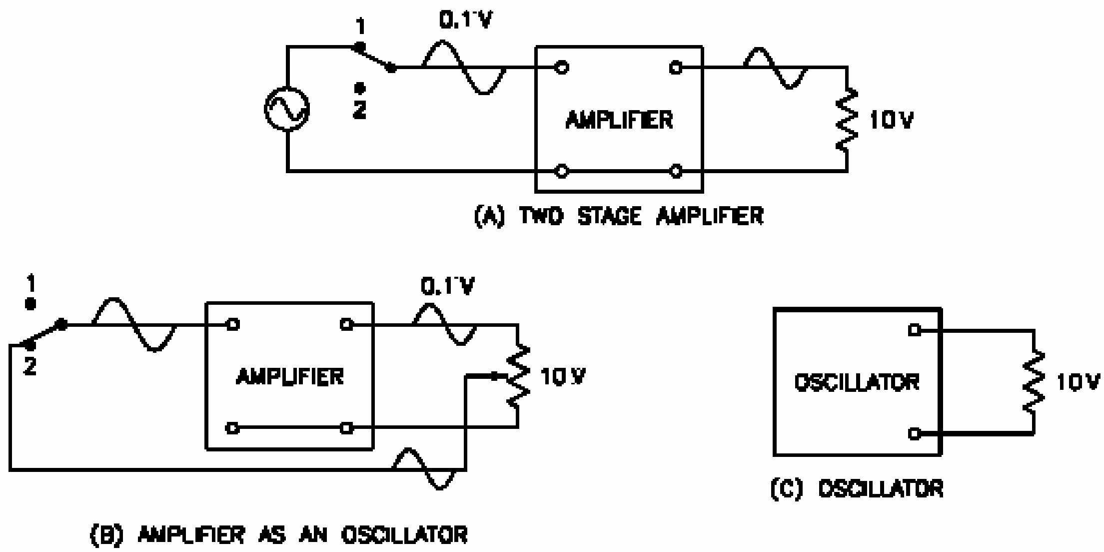


Figure 1. Amplifier as an Oscillator

RC oscillators are considered to be audio frequency oscillators, because they can produce an output frequency as low as 20 Hz. However, their upper frequency limit is far beyond the audio frequency range.

The RC Phase Shift Oscillator

The RC phase shift oscillator uses an RC phase shifting network to provide regenerative feedback from the collector to the base of a single transistor. The circuit consists of only one transistor amplifier plus a phase shift in proportion to the frequency passed through it. Phase shift oscillators are used where a fixed frequency is desired. The output waveform is very nearly sinusoidal and, if the amplitude and the output are held to a low level, the frequency stability is very good. The heart of the oscillator is the amplifier. The amplifier shown in Figure 2(A) has a gain of 30 and, therefore, produces an output of 3 volts when 0.1 volts is applied to its input terminals as shown. It differs from a conventional amplifier only in that its load resistor has a phase shifter connected in parallel with it. In the process of providing the necessary 180^0 of feedback, the output signal is also attenuated. It is a characteristic of the phase shifter that it produces exactly these effects at one frequency only. At any other frequency, the output will be less than 0.1 volt, and its phase will be shifted by more or less than 180^0. At the one frequency determined by the phase shifter, however, its output is exactly in phase with the amplifier input voltage.

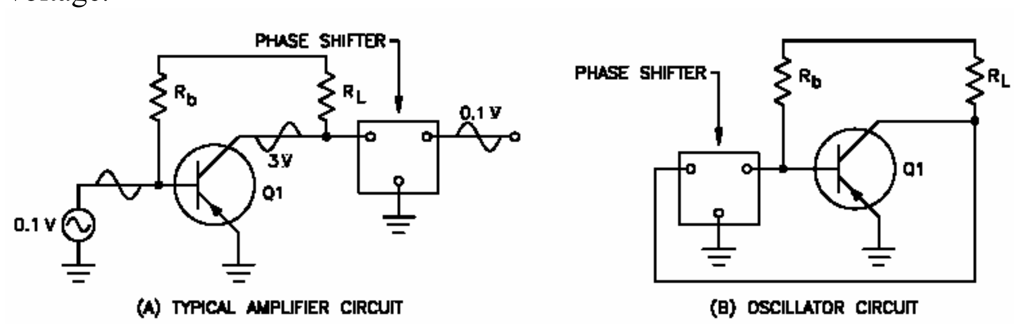


Figure 2. Basic RC Phase Shift Oscillator

The oscillator is redrawn in Figure 2(B) with the phase shifter shown in a conventional manner on the base side of the amplifier. The 0.1 volt output of the phase shifter has been substituted in the circuit for the 0.1 volt external input signal. This meets the requirements for oscillation of an amplifier explained in the preceding paragraph. A portion of its output voltage has been fed back to its input terminals in proper amplitude and phase. The requirements for a circuit to act as an oscillator are amplification, regenerative feedback, and a frequency determining network.

The L-Type Phase Shifter

The L section consists of a capacitor and a resistor in series and produces a phase shift of 60^o between the input voltage and the output voltage. An alternating voltage from the collector circuit is applied to the input terminals of the phase shifter, and a current flows through the series RC circuit. The resulting voltages are represented by the vector diagram in Figure 3(B).

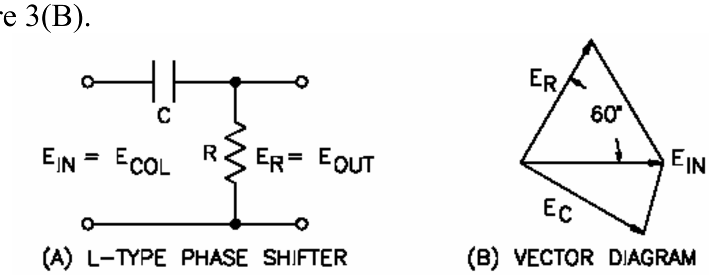


Figure 3. Principle of Phase Shifter

The three L-sections that make up the phase shifter are shown in Figure 4. The output of section 1 is applied to the input of section 2, its output in turn is applied to the input of section 3, and its output in turn is applied to the base circuit, after having undergone a total phase shift of approximately 180^o. The amplifier must have a high gain for a high output because the phase shifter provides only 0.1 volt output for approximately 3 volts input. The voltage is attenuated by a factor of about 30 for a 3-section phase shifter and about 20 for a 4-section phase shifter. All capacitors and resistors in the phase shifter are normally the same value. That means that each section provides an equal portion of the phase shift.

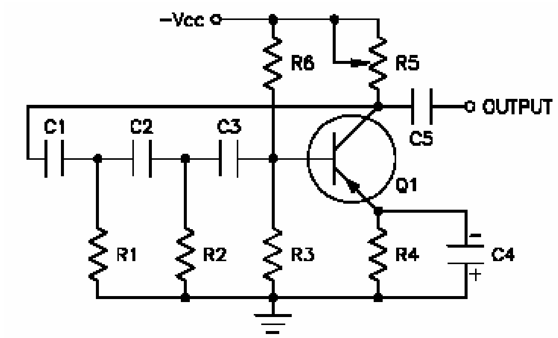


Figure 4. RC Phase Shift Circuit

Practical Operation of the Phase Shift Oscillator

Refer to Figure 4.

1. Transistor Q1 operates as an amplifier and is biased for Class A operation.
2. Resistor R6 provides the correct amount of base current to the transistor.
3. Resistor R5 is the collector load resistor; it develops the output signal and is adjustable to compensate for circuit variations.
4. Capacitor C1 and resistor R1 serve as the input side to the phase shifter, which provides approximately 60^0 of phase shift. This is considered section 1.
5. Capacitor C2 and resistor R2 also provides about 60^0 of the phase shift. This is considered section 2.
6. Capacitor C3 and resistor R3 form the output side of the phase shifter. R3 is also part of the transistor bias stabilizing circuit. C3 and R3 also provide 60^0 of phase shift. This is considered section 3.
7. Capacitor C4 and resistor R4 are the emitter resistor and bypass capacitor. The bypass capacitor prevents degeneration of the output signal.
8. Capacitor C5 is the output coupling capacitor to the next circuit. Capacitor C5 also functions as a DC blocking capacitor.

Circuit Operation

Refer to Figure 4. Assume that all circuit connections are made and the oscillator circuit is performing properly. A positive-going signal on the base of Q1 decreases the collector current. This decrease in the collector current causes a decreased drop across R5, causing the collector voltage of Q1 to go more negative. Because a positive-going signal appears in the output circuit as a negative-going signal, the signal is reversed in phase, or phase shifted by 180^o. The signal at the collector is then applied to the phase shifting network; it is returned to the base circuit after it has been shifted 180^o by the transistor amplifier and reshifted approximately 180^o by the phase shifting network. The feedback is now of the proper phase and amplitude to sustain oscillations.

The Output Waveform

The RC oscillator produces a sinusoidal waveform of a fixed frequency because the phase shifting network is made of fixed values of resistance and capacitance. The resistors or capacitors can be made variable to provide a variable output frequency over a limited range.

Operating Frequency

The approximate operating frequency of the phase shift oscillator can be determined by applying the formula:

$$f = \frac{1}{2\pi(R_1C_1 + R_2C_2 + R_3C_3)}$$

RC is the time constant of one section of the phase shifting network. If all sections are identical, a more accurate formula for determining frequency is:

$$f = \frac{1}{2\pi 3(RC)}$$

Phase Relationship

Figure 5 illustrates the phase relationship of the phase shifting network waveforms in an ideal circuit.

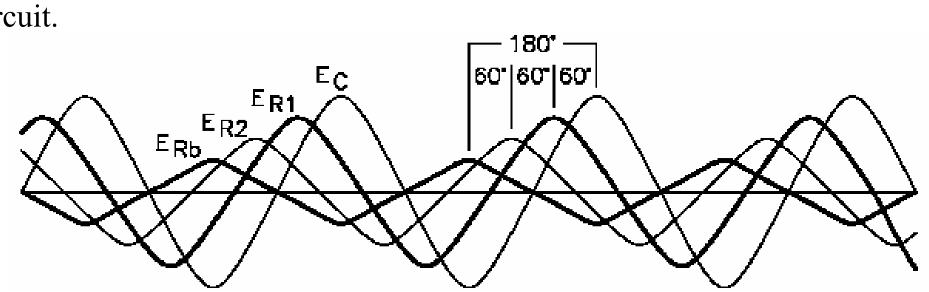


Figure 5. Phase Shifter Waveforms

EXPERIMENT

The purpose of this experiment is to illustrate the operational characteristics of the RC phase shift oscillator.

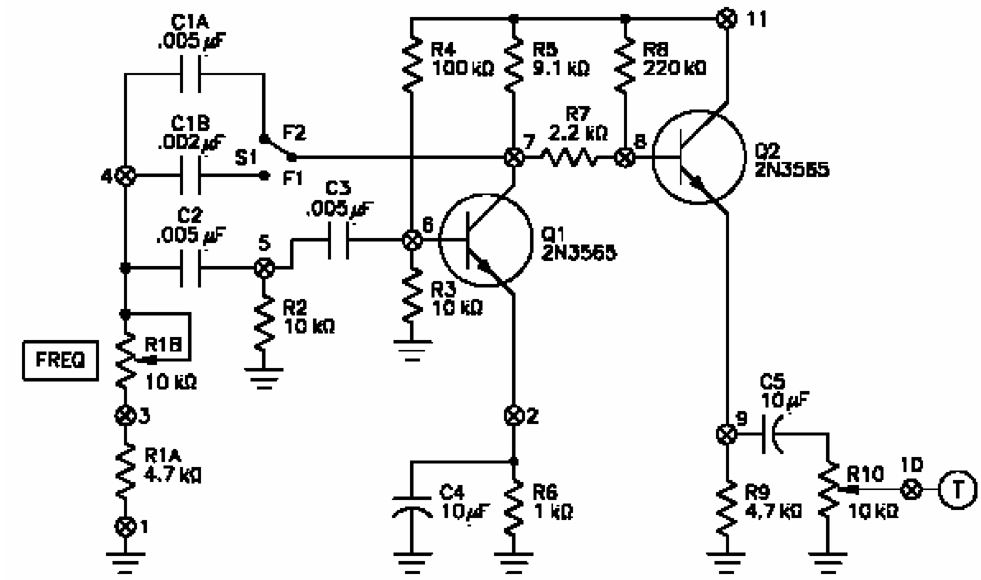


Figure 6. PC130-37 RC Phase Shift Oscillator

PREPARATION

The experiment card to be utilized is shown in Figure 6. The experiment will be performed only on the RC phase shift oscillator.

1. The S1 switch on the card permits changing one of the RC networks to change the output frequency. Variable resistor R1B also provides for changing the resistance in the first RC network, which also changes the output frequency.
2. When capacitor C1B is connected by the S1 switch, the feedback capacitors are not all of the same value and the phase shift will not be the same in each RC network.
3. When R1B is adjusted, the sum of R1A and R1B is not 10 kilo-ohms, the feedback resistors will not all be equal and the phase shift will not be the same in each RC network.
4. Regardless of the individual R and C values, the overall phase shift must be approximately 180^0 for the circuit to oscillate. The three phase shift networks of the phase shift oscillator are usually the same value, but it is not a requirement for the circuit to produce oscillations.
5. Transistor Q1 and its components are the oscillator circuit. Transistor Q2 is an emitter follower isolation circuit that isolates the output terminal from the oscillator. With this arrangement, the load will not affect oscillator operations. Variable resistor R10 permits the adjustment of the output signal at the desired amplitude.

PROCEDURE

1. Set the test console POSITIVE and NEGATIVE SUPPLY controls to OFF and turn the console POWER switch to ON.
2. Insert experiment card PC130-37 in the PC1 connector and set the S1 switch to the F1 position.
3. Check the AC power connections to the oscilloscope and turn POWER ON.
4. Connect an ohmmeter between TP4 and ground, and adjust variable resistor R1B for a 10 kilo-ohmsreading.
5. Connect an ohmmeter between TP10 and ground, and adjust variable resistor R10 for 5 kilo-ohms.
6. Reset the test console.
7. Set the POSITIVE SUPPLY control for a +12 volt reading on the voltmeter.
8. Turn the PC1 DC POWER switch to ON.
9. Connect an external trigger to TP10 from the oscilloscope's BNC TRIGGER connector and set the triggering source to EXT.
10. Check the operation of the oscillator and insure that the circuit has an output on TP7.

Complete phase measurements as follows.

Note that the sine waves may be distorted. Check the maximum and minimum points along with the zero crossing points to draw the sine wave in Figure 7.

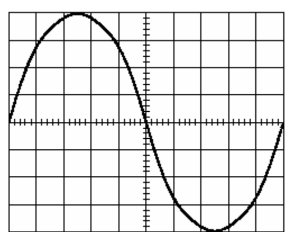


Figure 7. RC Phase Shift Waveform

a. Observe the collector waveform of Q1 (TP7) and adjust for the display as illustrated in Figure 7. (Use 1 VOLTS/DIV.)

Amplitude = ______________

b. Observe and record in Figure 7 the waveform (TP4) across the first phase shift network. (Use 0.2 VOLTS/DIV.)

Amplitude = ______________

c. Observe and record in Figure 7 the waveform across (TP5) the second phase shift network. (Use 0.1 VOLTS/DIV.)

Amplitude = ______________

d. Observe and record in Figure 7 the waveform across (TP6) the third phase shift network. (Use 0.1 VOLTS/DIV.)

Amplitude = ____________

Notice this waveform is 180o shifted from the collector waveform on TP7.

e. What was the total phase shift across the three phase shift network?

____

f. Connect Ch1 to TP7 and measure the frequency. (You may use a frequency counter if available.)

Measured F1 ____________

g. Calculate the frequency using the formula in the lesson and the values indicated in Figure. Note that R1B and R1A were set to 10 kW.

Calculated F1 = ____________

Notice that the measured frequency is within ±15% of the calculated frequency. The purpose of R1B is to change the frequency to produce the required frequency.

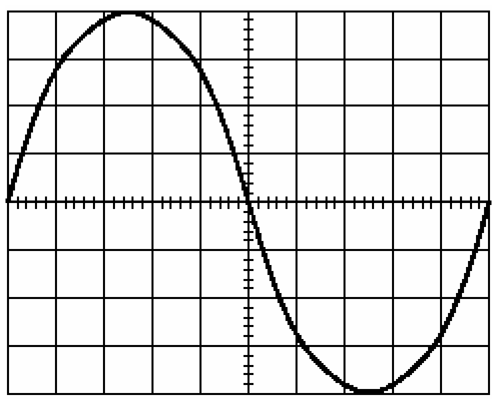


Figure 8. RC Phase Shifter Waveforms with Different Value Capacitor

h. Set the S1 switch to F2 and repeat Steps 10a through 10d above. Record the phase shift in Figure 8.
TP4 use 0.5 VOLTS/DIV
TP5 use 0.2 VOLTS/DIV
TP6 use 0.1 VOLTS/DIV

i. What was the overall phase shift?

____

j. What conclusion can be made about the phase shift network of the phase shift oscillator?

____

k. Connect Ch1 to TP7 and measure the frequency. (You may use a frequency counter if available.)

Measured F2 = ____________________

l. Calculate the frequency using the formula in the lesson and the values indicated in Figure 6. Note that R1B and R1A were set to 10 kW.

Calculated F2 = ____________________

11. Set switch S1 to F1. What is the range of frequencies that is available by adjusting the variable resistor R1B? Use an oscilloscope or frequency counter connected to TP7.

(f) min ______________ (f) max ______________

Notice how R1B can be used to make minor adjustments to the frequency.

12. Measure the DC operating voltages:

(Q1) V_C (TP7) = ______________ (Q2) V_C (TP11) = ______________

V_B (TP6) = ______________ V_B (TP8) = ______________

V_E (TP2) = ______________ V_E (TP9) = ______________

13. This is the conclusion of the phase shift oscillator experiment. Turn off all power and return the POSITIVE and NEGATIVE SUPPLY controls to OFF. Remove PC130-37 from the PC1 connector. Return all equipment to its designated storage area.

SUMMARY

- The RC phase shift oscillator uses resistors and capacitors to provide the necessary phase shift feedback.
- An oscillator is an amplifier that derives its input signal from its own output signal.
- The shift network in the RC oscillator provides approximately 180^o of feedback.
- The phase shift oscillator uses a minimum of three L-type RC sections for the phase shifting network.
- Each section of the L-type network provides approximately 60^o of phase shift.
- The phase shift oscillator is commonly used in the audio frequency range.
- Before power is applied to a transistor circuit, bias voltage and polarity must be checked to insure that they are correct.

- Oscillators using resistance/capacitance circuits to provide phase shift and feedback usually operate Class A.
- The output frequency of an RC phase shift oscillator may be changed by varying the resistance or capacitance in the phase shift circuit.
- Transistor circuits are easy to troubleshoot, providing the proper procedures and test equipment are utilized.

EXERCISES

1. The phase shift oscillator uses ____________ and ____________ to provide in-phase feedback.

2. Each L-type section of the phase shift network produces approximately ______________ of feedback.
   a. 30^o
   b. 50^o
   c. 60^o
   d. 90^o

3. The RC phase shift oscillator uses _____________________ transistor(s).

4. To produce the necessary 180^o feedback, the phase shift uses __________________ L-type sections.

5. Assuming 30 volts input to the RC phase shift network, the output will be approximately ________________ volt(s).
   a. 15
   b. 10
   c. 3
   d. 1

6. In the phase shift oscillator, the minimum number of RC sections that can be used in the feedback circuit is __________________ .
   a. one
   b. two
   c. three
   d. four

7. What class of operation is used in oscillators using RC networks to provide phase shift and feedback?

   a. Class A
   b. Class B
   c. Class C
   d. Class D

8. The three L-type phase networks in the phase shift oscillator must use the same value components.

   a. True
   b. False

9. How many different frequencies will be shifted by exactly 180^{o} through the RC network?

   a. 1
   b. 2
   c. 3
   d. 4

10. The three requirements to sustain oscillation in an oscillator at a given frequency are ____________________ , ____________________ , and ____________________ .

Lab Session 09

OBJECTIVES

1. Identify the schematic diagram and symbol for the FET crystal oscillator.
2. Describe the operating characteristics of the FET crystal oscillator.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-50
- Oscilloscope
- Multimeter
- Frequency Counter or equivalent (OPTIONAL)

OVERVIEW

In this lesson, the student will learn about FET crystal oscillators. Resonant circuits which use inductance and capacitance have problems with frequency drift. Drift can be caused by changes in temperature, voltage variations, or aging of components. If the transmitter frequency should drift or change, the signal at the receiver will also drift or be totally lost. Drifting problems may cause the receiver oscillator to drift off the assigned frequency and lose reception of the transmitted signal. When drift-free transmissions must be generated, a crystal oscillator may be the solution. Crystal oscillators have excellent frequency stability. A drawback is that a crystal oscillator cannot be tuned over a range of frequencies and must be fixed to a single frequency.

INTRODUCTION

Quartz crystals are commonly used as the frequency determining circuit in crystal oscillators. Other kinds of crystals are occasionally used, but quartz is the most commonly chosen. Crystals can be used in oscillators because they exhibit the piezoelectric effect. When a mechanical pressure is placed on the plates of a crystal, the crystal develops a voltage difference across its plates. If the direction of the pressure is reversed, the polarity of the voltage will be reversed. If the pressure is constantly alternated, an alternating voltage will be developed across the plates of the crystal.

When an alternating voltage is applied across the plates of a crystal, the crystal will vibrate at a frequency that is dependent on its physical dimensions. If the voltage is applied periodically, the crystal will vibrate continuously and develop an AC voltage across it that is similar to that developed by a resonant circuit. This is known as the piezoelectric effect. The natural vibrating frequency of a crystal depends on its size and how it was cut from the basic crystal material. The vibrating frequency is mostly determined by the thickness of the crystal. The thinner the crystal, the higher its natural vibrating frequency. This places the upper limit on the vibrating frequency of a crystal at approximately 50 MHz.

The FET As A Crystal Oscillator

A FET is normally used as a high frequency crystal oscillator because of its low internal capacitance, high interlead resistance, and its ability not to load down the input signal. A conventional transistor may be used for high frequency applications requiring careful layout design; however, the FET is more adaptable for this application. A popular FET crystal oscillator is the Pierce oscillator. The circuit is similar to the Colpitts oscillator, where an amplified signal 180 degrees out of phase is returned to the lower part of the resonant circuit, while the original signal to the amplifier is sent to the input of the **amplifier** from the top of the resonant circuit. This double 180-degree phase shift causes a positive feedback to sustain oscillations. In the Pierce oscillator, an amplified signal 180 degrees out of phase is returned to one side of the crystal, while the other side of the crystal furnishes the input signal to the amplifier.

At high frequencies, whether in an oscillator or amplifier circuit, stray capacitance becomes a problem. In an ordinary LC circuit, stray capacitance can cause a shift in resonant frequency and output amplitude. In a crystal oscillator, stray capacitance may cause a change in output amplitude but will not cause a change in frequency. This is one of the benefits of a crystal oscillator, as resonant frequency is a function of the crystal physical size and is not affected by the circuit's electrical values.

The FET Crystal Oscillator

Figure 1 is the schematic diagram of a FET crystal oscillator. Its operating characteristics are described as follows: The letter Y is commonly used to denote a crystal on a schematic diagram. In Figure 1, Y1 is the crystal cut to operate at a specific frequency. Y1 will control the frequency of oscillations. Note that in a crystal oscillator, a minimum number of components are required in the circuit.

Q1 is the amplifier. Q1 is a dual gate, N channel, depletion type field effect transistor (MOSFET). It is a voltage amplifier and provides the gain required to sustain oscillations. The two gates are connected together to function as a single gate device. The gate is insulated from the channel and therefore does not draw current, regardless of the potential on the gate with respect to either source or drain. The gate potential develops an electrostatic field in the channel that increases current flow when it is positive and decreases current flow when it is negative. An AC signal on the gate will alternately increase and decrease the channel current. Since Q1 is an N type channel device, electrons flow from the source to the drain when an operating voltage is applied. The amount of current flow depends on the applied voltage, the resistance or opposition in the current path, and the potential on the gate. Regardless of the potential on the gate, the gate does not draw current from the channel, so there can be no build-up of bias on the gate terminal. Bias is developed across the source resistor R2, which is self bias. Self bias cannot cause current cut-off, so the transistor will operate as a Class A amplifier.

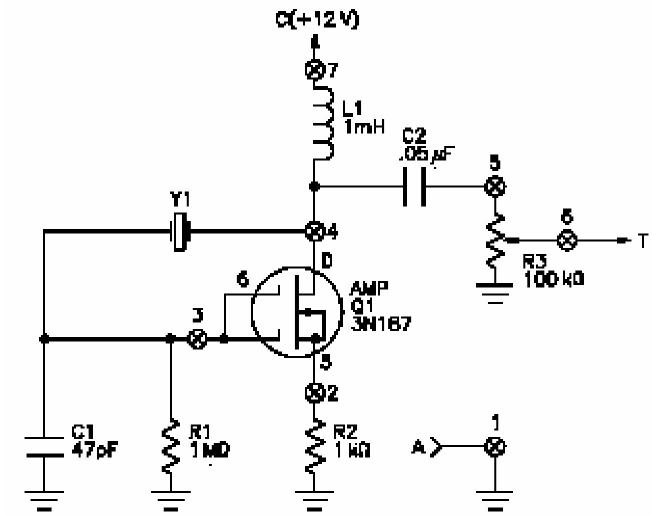


Figure 1. FET Crystal Oscillator

Inductor L1 is a radio frequency choke (RFC) across which the output signal and regenerative feedback is developed. The three main requirements for sustained oscillations at a specific frequency have been met: (1) Q1 is an amplifier, (2) L1 develops the regenerative feedback, and (3) Y1 is the frequency determining circuit (or resonant circuit). When power is applied, the drain becomes positive through L1, and current flows from the source to the drain. The source current through R2 establishes the self-bias for Q1. Drain current through L1 develops a voltage drop which is applied to the crystal Y1. The negative change on the drain side of the crystal is felt as a positive change on the gate side of the crystal, which is regenerative feedback. As the current reaches maximum, the crystal begins to vibrate, reversing the polarity on the gate and decreasing the drain current. The rising drain voltage aids the vibration of the crystal. The crystal vibrations cause the gate potential to vary at a sinusoidal rate which is equal to the crystal vibrating frequency. Therefore, the oscillating frequency is directly controlled by the crystal frequency. Capacitor C1, along with the capacitance of the Y1 crystal holder, form an AC voltage divider to limit the feedback signal applied to the crystal to a safe value. If the regenerative feedback to a crystal is excessive, the crystal will vibrate excessively and may be damaged. This is a limitation when using crystals. Resistor R1 is the gate return resistor that keeps the gate at ground or zero volt potential as a reference. Capacitor C2 and variable resistor R3 are the output circuit. R3 is variable so the output signal level can be adjusted. This circuit is designed to operate as a Class A amplifier because of the characteristics of the MOSFET transistor. If a bipolar transistor was used, the base could draw current to develop base leak bias and the circuit would operate Class C. Crystal oscillators can operate under any class of operation, depending on the circuit components and configuration.

EXPERIMENT

This experiment will illustrate the special characteristics of the FET crystal oscillator.

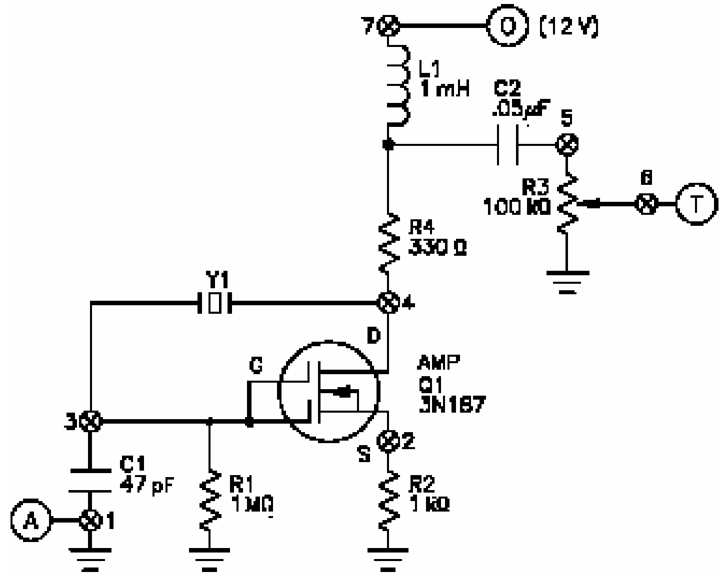


Figure 2. Experiment Card PC130-50

PREPARATION

Figure 2 represents the schematic diagram of experiment card PC130-50. A MOSFET transistor is used as the amplifier because of the simplicity of bias requirements and low interelectrode capacitance. Self-bias is used to establish DC operating voltages for Q1. The operation of self-bias for a JFET and MOSFET are identical, where VRS equals the reverse bias across the GS diode. Because the DC load on Q1 drain is an inductor, the operating point of V_D equals 12 volts, or V_{DD}. Consider Y1 as a parallel resonant circuit. When DC power is applied, the crystal will draw current from V_{DD}. This will energize the crystal and vibrations begin. A small vibration will cause a momentary positive voltage on one side of the crystal and negative voltage on the other side. If the Q1 gate is driven positive, Q1 drain will amplify and invert the signal. This larger negative voltage at Q1 drain is fed to the other side of the crystal to reinforce the positive voltage on the Q1 gate side, and oscillation begins as in an LC resonant circuit.

PROCEDURE

1. Set the test console POSITIVE and NEGATIVE SUPPLY controls to OFF. Turn the console POWER switch to ON.
2. Insert the PC130-50 card into the PC1 connector. Set R3 fully counter-clockwise (minimum).
3. Reset the test console.

4. Adjust the POSITIVE SUPPLY control for a +12 volt reading.
5. Turn the PC1 DC POWER switch to ON.
6. Make voltage measurements and calculations to complete the data required in Table 1 for a V_{DD} reading of 12 volts. Then decrease the POSITIVE SUPPLY to 5 V and fill in Table 1 for a V_{DD} of 5 V.

NOTE:

The MOSFET is a high impedance device. The oscilloscope probe may tend to load the circuit and cause distortion of waveforms. Under some conditions, the gate waveform may not be present when the oscilloscope is connected. It is also possible that distortion will occur in the source waveform. When viewing waveforms in high impedance circuits, you should utilize high impedance probes or low capacitance probes if available. Use a X10 probe.

TABLE 1. Crystal Oscillator Operating Characteristics

	V_{DD} = 12 V	V_{DD} = 5 V
OUTPUT (TP4) ______ V_{PP} at 12 V ______ V_{PP} at 5 V	(Draw Waveform)	(Draw Waveform)
GATE (TP3) ______ V_{PP} at 12 V ______ V_{PP} at 5 V	(Draw Waveform)	(Draw Waveform)
VDC drain (TP4)		
VDC gate (TP3)		
VDC source (TP2)		
Frequency		

7. While observing the output signal at TP5 with the oscilloscope, vary V_{DD} to 5, 12, 15 and then back to 12 volts. Describe the results on:

a. Signal amplitude: ______________________

b. Output frequency: ______________________

c. Was the output frequency stable or unstable? ______________

Notice from Table 1 that regardless of V_{DD} the output frequency remains the same. This is the main reason crystal oscillators are used, for frequency stability. Also notice that the DC voltages measured at the drain gate and source are values which indicate normal FET operation. This circuit exhibits a slight voltage gain above V_{DD} for the output AC waveform.

8. This completes the experiment. Return the POSITIVE and NEGATIVE SUPPLY controls to OFF. Turn the console POWER switch to OFF and remove PC130-50. Return all equipment to its designated storage area.

SUMMARY

- Resonant circuits using inductance and capacitance have problems with frequency drifting. The drift in frequency can be caused by temperature, voltage variations, or aging of components.
- To overcome drift free oscillations, the crystal oscillator may be used. The stability of the crystal oscillator is excellent.
- Any type of bipolar transistor amplifier can be used as a crystal oscillator. But these types of amplifiers are very sensitive to temperature variations. In some cases where a bipolar transistor amplifier is used as a crystal oscillator, the entire unit is placed in an oven where the temperature is controlled.
- In many applications, the conventional bipolar amplifier cannot be utilized as a crystal oscillator. In this event, a FET transistor is utilized.
- Using the FET transistor operational characteristics at high frequencies is better than using the bipolar transistor, but the FET device is very sensitive to interelectrode capacitance.
- The design of a crystal oscillator using a FET requires careful layout and minimum use of components to prevent interelectrode capacitance.

EXERCISES

1. A crystal can be used as the ______________________________ network of an oscillator.

2. Crystal oscillators have a __________________________________ frequency stability.

3. A higher frequency can be obtained by using a crystal oscillator.
   a. True
   b. False

4. If a crystal is said to have a positive temperature coefficient, the temperature of the crystal will _____________________ .
   a. rise with a rise in temperature
   b. rise with a decrease in temperature
   c. fall with a rise in temperature
   d. fall with a decrease in temperature

5. The letter ______________ commonly designates a crystal in a circuit.
   a. W
   b. Y
   c. X
   d. Z

6. In a common source FET circuit, electrons flow from ______________ .
   a. the source to the gate
   b. the source to ground
   c. the source to the drain
   d. the source to the collector

7. Regardless of the potential at the gate in the MOSFET, the gate does not draw current.

   a. True
   b. False

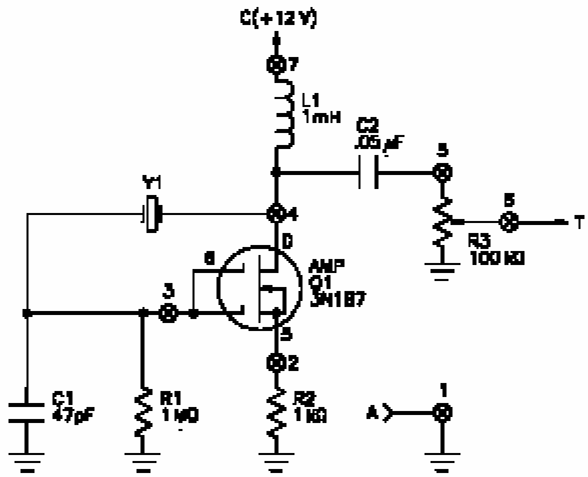


Figure 5. FET Crystal Oscillator

8. Refer to Figure 5, reproduced above. Regenerative feedback is developed across ________________ .

   a. C2
   b. L1
   c. R3
   d. R2

9. In Figure 5, the component that establishes self-bias for Q1 is ________________ .

   a. L1
   b. R2
   c. R3
   d. R1

10. Crystal oscillators can operate as ________________ .

    a. Class A amplifiers
    b. Class B amplifiers
    c. Class C amplifiers
    d. all of the above

Lab Session 10

OBJECTIVES

1. Identify schematic symbols of a unijunction transistor oscillator.
2. Describe the operating characteristics of a unijunction transistor oscillator.
3. Observe normal operation in a UJT oscillator circuit.

EQUIPMENT REQUIRED

- Nida Model 130E Test Console
- Nida Series 130 Experiment Card : PC130-51
- Oscilloscope
- Multimeters
- Cable, BNC to Alligator

INTRODUCTION

This lesson introduces you to a specialized transistor, the unijunction transistor. The unijunction transistor is one of many specialized semiconductor devices developed by the electronic revolution. The application of the unijunction transistor solves many complex design requirements with a minimum number of components. Specialized components such as the UJT have allowed the design of more complex equipment for less cost.

Unijunction Transistor Characteristics

UNIJUNCTION TRANSISTOR - is a three terminal semiconductor device having linear resistance characteristics. When first designed, a UJT was called a double based diode. Figure 1 is a comparison between the block diagrams of a transistor and a UJT. From the comparison, differences become readily apparent:
1. The transistor has two junctions, and the UJT has only one.
2. The transistor consists of three blocks of material (NPN or PNP), and the UJT has one unbroken block of material. That one block of material acts as a resistor, resulting in a voltage drop over it.
3. A transistor has non-linear resistance, while a UJT has linear resistance.

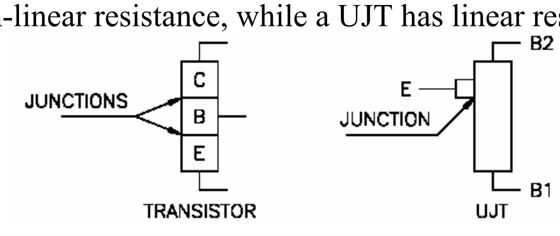


Figure 1. Transistor and UJT Block Diagrams

Figure 2 illustrates the schematic symbols for the transistor and UJT. In both semiconductors, the arrow indicates the emitter and points toward the element constructed from N material. Notice that there are two symbols for the transistor (NPN, PNP) and only one for the UJT. That is because the UJT is always constructed from a block of N material for the base and a block of P material for the emitter.

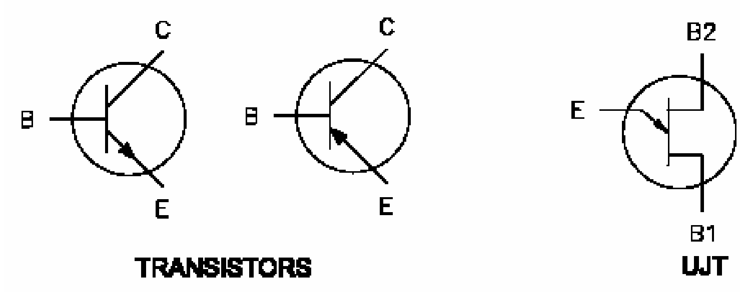


Figure 2. Transistor and UJT Schematic Symbols

UJT Operation

Why a UJT? First, a UJT is very stable over a wide range of temperatures. Also, when conventional transistors are replaced, fewer components are needed.

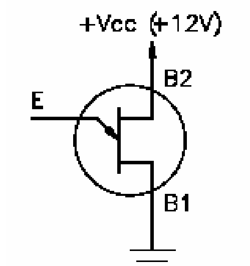


Figure 3. UJT Base Bias

Just as the transistor requires proper bias to operate, so does the UJT. Figure 3 depicts the typical bias for a UJT. B2 must be more positive than B1. The emitter must have a certain bias with B1 for conduction to occur. As was stated earlier, the base material exhibits linear resistance. Unless the UJT is forward biased, it acts like an open. When it is properly biased, it conducts heavily (almost saturation) from B1 to the emitter. Forward biasing is a little different than it was in other semiconductors. Figure 4 depicts the internal electrical characteristics of a UJT. As was stated earlier, a UJT exhibits resistance and has a voltage drop. The UJT in Figure 4 has ground applied to B1 and +12 volts DC to B2.

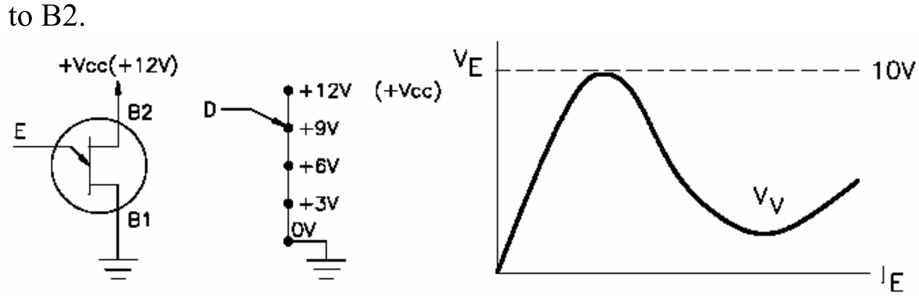


Figure 4. Internal Electrical Characteristics **Figure 5. UJT Conduction of the UJT**

Theoretically, if a meter could be inserted at one of the points inside the device, a smaller voltage would be measured. As an example, if the voltmeter could be placed across ground and point D, you would measure +9 volts DC. When a UJT is constructed, the required potential for forward bias between B1 and the emitter is determined by the manufacturing process. That required bias is called the voltage gradient. The voltage gradient for the UJT in Figure 6 indicates that forward bias occurs when the emitter is 9 volts more positive than B1. If the emitter voltage is less than the required 9 volts, the UJT acts like an open. If the emitter voltage increases to 9 volts or greater, the emitter–B1 junction is forward biased and the device conducts almost at saturation. Figure 5 graphs the conduction of the UJT in Figure 6. The vertical line represents the voltage applied to the emitter. The horizontal line represents the emitter current. For this illustration, 10 volts is applied to the emitter of the UJT (Vpeak, VE). As the voltage gradient is greater than the applied voltage, the device is forward biased. That causes the UJT to conduct heavily. The heavy conduction causes a decrease in emitter voltage, due to Ohm's Law. Remember, a UJT acts like a resistor. As emitter current increases, emitter voltage decreases. When the emitter voltage decreases below the voltage gradient, the UJT becomes reversed biased and forward conduction stops.

UJT Oscillator

Figure 6 illustrates an astable multivibrator constructed from a UJT. As is readily apparent, a major advantage in the application of UJTs is the reduced number of components in a circuit.

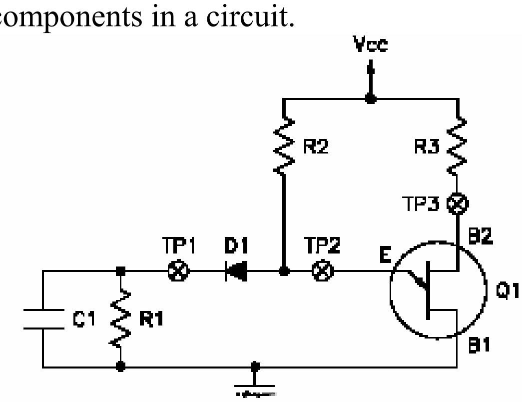


Figure 6. UJT Multivibrator

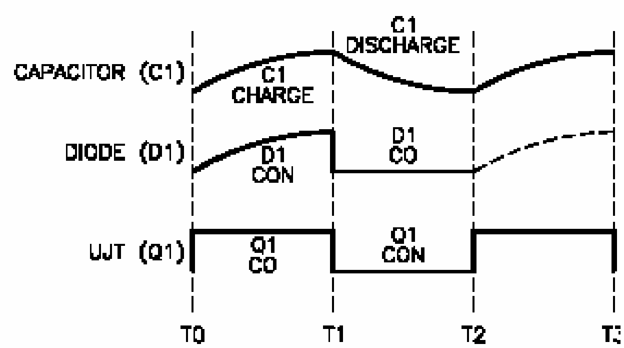


Figure 7. UJT Multivibrator Timing Diagram

The entire operation of the circuit is based on the voltage gradient of the UJT. When the charge on C1 exceeds the potential required to forward bias Q1, Q1 turns on and discharges C1. The sequence of events in the operation of UJT multivibrators is as follows:

When power is first applied to the circuit, Q1 is cut off. That is because there is VCC on B2, ground on B1, and 0 volts on the emitter – Q1 is not forward biased. C1 begins to charge from ground to C1, through the forward biased D1, to R2, to VCC. The instant the charge on C1 is great enough to bring Q1 into conduction, the UJT is forward biased. Q1 goes into conduction, reverse biasing D1. Reverse biasing D1 cuts off C1 from its source, stopping its charge. C1 then begins to discharge through R1. When the charge on C1 decreases enough, D1 is once more forward biased. That action cuts off Q1, and C1 begins to charge. Q1's conduction path is from ground, Q1's base 1 to emitter, through R2 to VCC. The frequency of the multivibrator is determined by the RC time constant of C1 and R1. Figure 7 is a timing diagram for the UJT multivibrator. The output of the multivibrator is VCC when Q1 is cut off and almost 0 volts when Q1 conducts. The astable multivibrator can be converted to a trigger circuit by changing a few components. Figure 11 is a UJT trigger circuit.

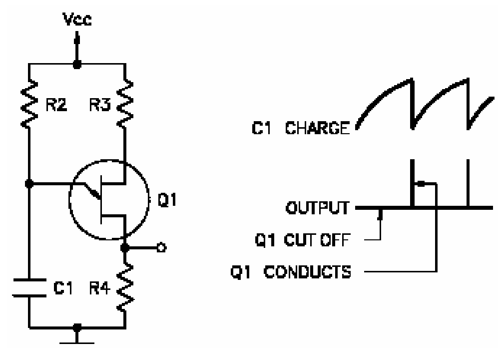


Figure 8. UJT Trigger Circuit

To convert from an astable to a trigger circuit, D1 and R1 have been removed. R4 has been added from B1 to ground. The circuit operates the same as the multivibrator. Q1 is cut off until the charge on C1 is of a sufficient value to bring Q1 into conduction. C1 charges slowly through R2 until Q1's conduction point is reached. Q1's conduction causes C1 to rapidly discharge through R4. The result is a spike or trigger at the output of the circuit. The frequency of the resulting triggers is determined by the RC time constant of C1 and R2.

EXPERIMENT

In this experiment, you will investigate how a UJT operates. You will observe waveforms and measure voltages on the PC130-51 circuit card.

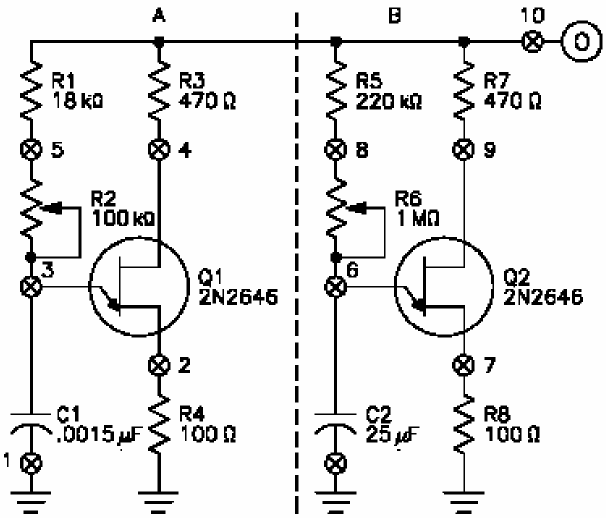


Figure 9. Circuit Connections For UJT Oscillator and Internal Timer Circuits

PREPARATION

Examine PC130-51. Notice that the circuit card contains two complete UJT oscillator circuits. Both circuits contain a variable resistor so the output frequency is adjustable by changing the circuit's RC time constant.

PROCEDURE

1. Set both SUPPLY controls to OFF, and turn the console POWER switch to ON.
2. Insert PC130-51 into the PC1 connectors.
3. Adjust the POSITIVE SUPPLY to 12 volts. This will set up the circuit which is illustrated in Figure 9.
4. Figure 9 is considered an oscillator because the time between repetitive waves is less than one second. Oscillation time is equal to RT x C. This is circuit A's RC time constant where RT = R1 + R2 and C = C1. Compute Figure 12 oscillation time for R2 set to MIN and MAX resistance. Record the results below:

Circuit A computed time, R2 set to minimum (0Ω) = R1 x C1 =

____

Circuit A computed time, R2 set to maximum (100 kΩ) = (R1 + R2) x C1 =

____

5. Connect the oscilloscope CH1 input probe to the RAMP output of circuit A (TP3) and ground to TP1. Set the 0 volt reference at VERTICAL CENTER. Set R2 fully CCW. Draw the resultant waveform on Figure 13 ERAMP. Indicate the MAX and MIN values in the blanks next to the waveform by setting the oscilloscope CH1 to

DC. This will slow the DC bias to turn the UJT on and the voltage to turn the UJT off. The waveform shows C1 charging towards +12 V when Q1 is off. When the voltage reaches the voltage gradient, Q1 turns on and discharges C1 quickly through Q1 emitter to base 1. When Q1 turns off, C1 begins to charge again. As long as power is applied, oscillations will continue.

6. Adjust R2 CCW and CW. Record the MIN and MAX cycle times in the blanks next to the waveform. Notice that the measured times are not exactly equal to the calculated times in Step 4.
7. The measured time depends on the voltage gradient of the UJT and the applied voltage. Connect the CH2 input to the ESPIKE output of circuit A (TP2). Retain the CH1 trigger. Set the CH2 0 volt reference at VERTICAL BOTTOM. Draw the resultant waveform on Figure 10 ESPIKE.

Notice that when Q1 is off (C1 charging) the base 1 voltage is 0 V. When Q1 turns on, a positive spike is developed, showing Q1 conducting.

8. Move the CH2 input to the EPULSE output of circuit A (TP4). Repeat Step 11 for Figure 10. Adjust the vertical position as necessary and retain CH1 triggering.

Notice that when Q1 is off, the voltage on base 2 is VCC or +12 V. When Q1 turns on, the voltage on base 2 decreases due to the increase in current through R3.

Figure 10. Waveforms in a UJT Oscillator Circuit

9. Set both SUPPLY controls to OFF, turn the console POWER switch to OFF, and return all equipment to its assigned storage area.

CONCLUSIONS

From your experiment results, you should conclude the following:

- A UJT remains cut off until the proper value of voltage is applied to the emitter.
- The switching time from cut-off to saturation is rapid.

SUMMARY

In this lesson, you have learned about unijunction transistor oscillators. Here are some important points to remember.

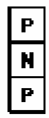
- The unijunction transistor is more commonly called a UJT.
- The UJT appears the same as a transistor, physically.
- UJT schematic symbols are different than transistor schematic symbols.
- The three elements of the UJT are the emitter, base 1, and base 2.
- The UJT always has an emitter constructed from P material and the base block from N material.
- Current flows in the UJT from B1 to emitter.
- The voltage gradient of a UJT determines the voltage required for forward bias.
- The voltage gradient of a UJT is determined at the time of manufacture.
- UJTs are used for multivibrators, switching pulse triggering, and oscillator circuits.
- A transistor has non-linear resistance, while a UJT has linear resistance.

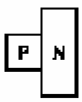
EXERCISES

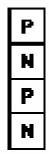
1. What does UJT stand for?
   a. Unified junction transistor
   b. Unijunction transfer
   c. Uniform transistor
   d. Unijunction transistor

2. Select the correct block diagram of a UJT.

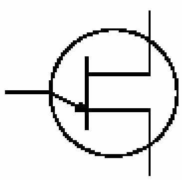
a. 

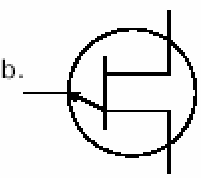
b. 

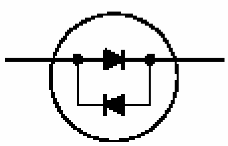
c. 

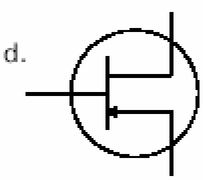
d. 

3. Select the correct symbol for a UJT.

a. 

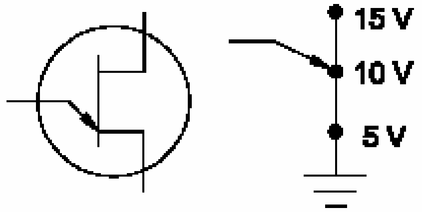
b. 

c. 

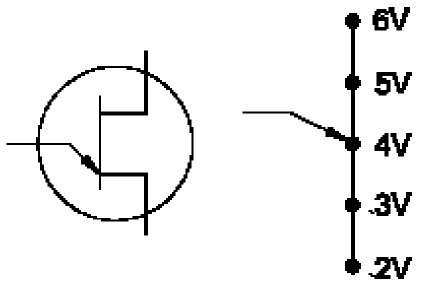
d. 

4. To what other electronic component can a UJT be compared?
   a. Resistor
   b. Capacitor
   c. Variable resistor
   d. Inductor

5. What must be the potential difference between the emitter and B1 for the UJT illustrated below to be forward biased?



6. What must be the potential difference between the emitter and B1 for the UJT illustrated below to be forward biased?



7. What type of resistance does a UJT exhibit?
   a. Non-linear
   b. Linear
   c. Forward
   d. None

8. Figure 14 is a ______________________________
   and Figure 15 is a ______________________________ .

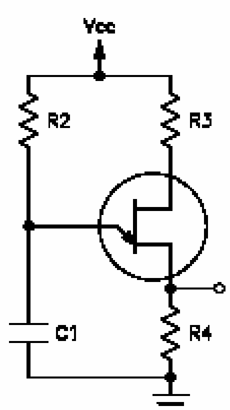


Figure 14.

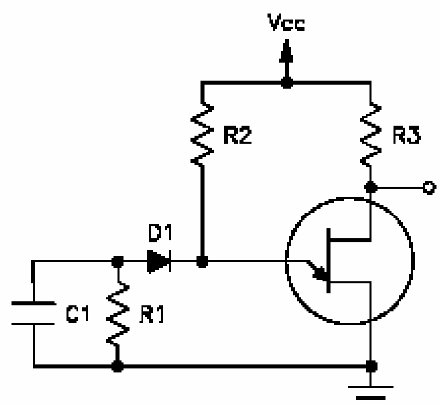


Figure 15.

Lab Session 11A

OBJECTIVES

1. Describe the purpose of the 555 Timer.
2. Describe the operation of the 555 Timer.
3. Observe the operation of the 555 Timer in Astable Mode.

EQUIPMENT REQUIRED

- Nida 130E Test Console
- Nida Series 130 Experiment Card : PC130-153
- Oscilloscope

INTRODUCTION

The proper operation of modern digital electronic systems requires accurate timing signals. A digital integrated circuit that was designed to provide accurate timing signals is the 555 Timer. To properly maintain complex digital electronic systems, the technician must be familiar with the types of circuits he will encounter. The 555 Timer is a simple, yet vital, IC that you will use in many advanced electronic devices. By understanding how this circuit operates, you will be better able to maintain digital systems.

555 TIMER

The importance of accurate timing in digital systems cannot be overemphasized. Without accurate timing, everyday appliances such as TVs, VCRs, stereos, and even cars would be unable to function. With digital circuitry becoming more common every day, a low cost, effective digital timer had to be developed. The 555 Timer is that digital circuit. The 555 integrated circuit is a very stable device that produces accurate time delays or oscillations. The output waveform of a 555 Timer is a square wave. Depending upon the number and location of external components, the 555 can be configured as an astable multivibrator, monostable multivibrator, pulse width modulator, pulse position modulator, or linear ramp generator. To accomplish all of those configurations, the 555 must have timing that is adjustable from microseconds to hours, operate in both the one-shot and free running modes, have an adjustable duty cycle, and be compatible with TTL circuitry. This lesson shows you how the timer is configured for an astable and monostable multivibrator. Figure 1 is the schematic symbol for the 555. As you can see from the diagram, it is available in both the DIP and can case styles. Pin 1 is ground, pin 3 is the output, and pin 8 is Vcc. The other pins and what the signals imdicate will be discussed later. In keeping with the versatile nature of the circuit, Vcc can vary from 5

V_{DC} to 15 V_{DC} without affecting circuit operation. The output current can be up to 200 mA, so the device can operate relays or lamps.

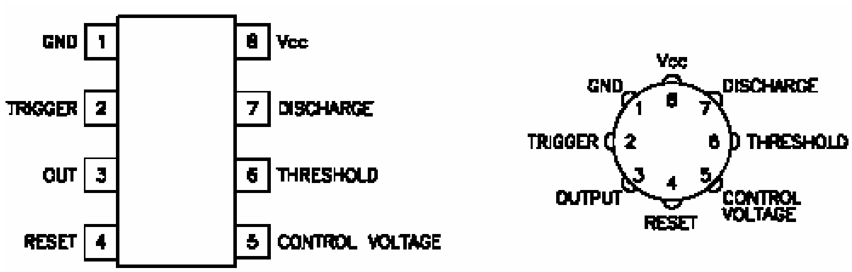


Figure 1. 555 Timer Schematic Symbol

555 TIMER CIRCUITRY

Figure 2 illustrates the internal circuitry of the 555 Timer to the block level. The heart of the timer is an RS flip-flop. The RS (Reset-Set) flip-flop is a very common digital circuit. It is basically a bistable multivibrator that has two inputs, R and S, and two outputs, Q and . In addition, the Q RS flip-flop has a RESET input. Flip-flops are taught in detail in Block 4 of this course. In general, the operation of the RS F/F is as follows:

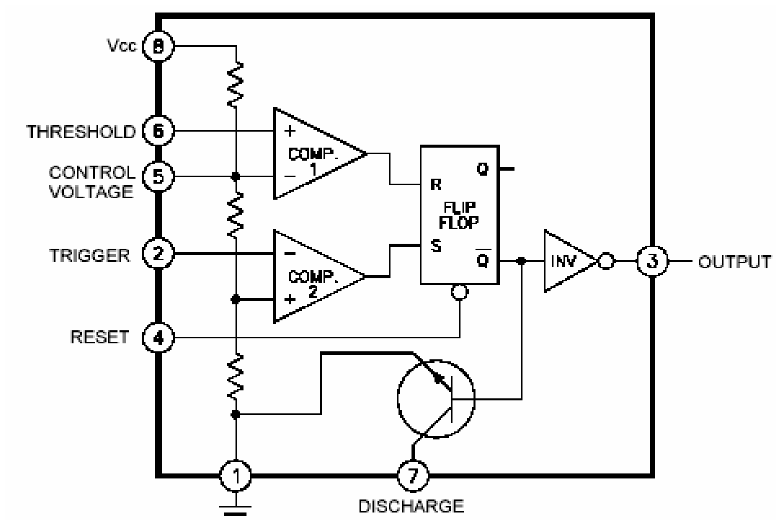


Figure 2. 555 Timer Block Diagram

A HIGH applied to the S input causes the Q output to be HIGH and the output to Q be LOW. A HIGH applied to the R input causes the Q output to be LOW and the output to Q be HIGH. A LOW applied to the RESET input causes the Q output to be LOW and the output Q to be HIGH, overriding inputs to R and S.

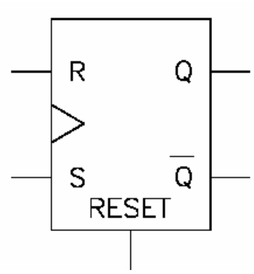


Figure 3. RS Flip-Flop

The RS inputs are provided by two comparators. Each comparator has two inputs. Comparator 1 has a threshold voltage applied to the + input and a control voltage applied to the - input. The purpose of comparator 1 is to compare the input threshold voltage to a fixed voltage. Because of the inputs, comparator 1 is called the threshold comparator. Comparator 2 has a trigger applied to the . input and a fixed voltage applied to the + input. The function of comparator 2 is to compare the input trigger to a fixed voltage. Comparator 2 is called the trigger comparator. How the 555 Timer operates depends upon the external components, voltages, and signals that are applied to the two comparators.

Under normal operation, the voltage on the threshold input (pin 6) is 2/3 Vcc and the trigger input (pin 2) is 1/3 Vcc. These voltage levels can be altered through external components and connections to the control voltage input (pin 5). When the voltage on the trigger input goes below the reference voltage (comparator 2 positive input), a HIGH is developed by the comparator and sent to the S input of the flip-flop. The flip-flop produces a HIGH Q output and a LOW Q' output. The Q' output is inverted, changed to a HIGH, and the output of the timer is HIGH.

When the voltage on the threshold input goes above the reference voltage (comparator 1 negative input), a HIGH is developed by the comparator and sent to the R input of the flip-flop. The flip-flop produces a LOW Q output and a HIGH Q' output. The Q' output is inverted, changed to a LOW, and the output of the timer is LOW.

Q1 is used as a switch to supply a ground to pin 7 (DISCHARGE). When the Q' output of Q the flip-flop is HIGH, Q1 is forward biased, connecting the ground on pin 1 to pin 7. When the output of Q' is LOW, Q1 is reverse biased, breaking the ground connection to pin 7. By using external components, specifically resisters and capacitors, to produce an RC time constant, the circuit in Figure 2 can be configured in many different ways. The following discussion describes two, the astable and monostable multivibrator.

555 TIMER ASTABLE MULTIVIBRATOR OPERATION

Figure 4 illustrates a 555 Timer configured as an astable multivibrator. An astable multivibrator is free running. That means as long as power is applied to the circuit, the output (pin 3) constantly changes states or flips from HIGH to LOW. To configure the device to operate as an astable multivibrator (also refer to Figure 2), the trigger and threshold inputs are connected together (pins 2 and 6). C1 charges through R1 and R2. C1 discharges through R2 by the action of the discharge output (pin 7) going LOW. The frequency of the multivibrator's output waveform is determined by the RC time constant of C1, R1, and R2. If a potentiometer is connected to the discharge path of the capacitor, the frequency of the output waveform becomes variable over a range of frequencies.

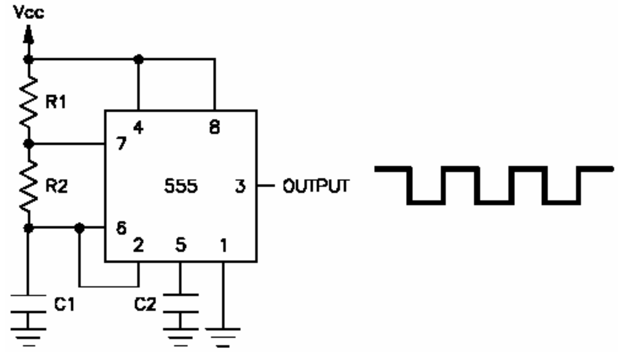


Figure 4. 555 Timer Astable Multivibrator

555 TIMER MONOSTABLE MULTIVIBRATOR OPERATION

Figure 5 is the schematic diagram of a 555 Timer configured as a monostable multivibrator. The only time the monostable, or one-shot, changes states is when it receives an input trigger (also refer to Figure 2). When the trigger input goes LOW, the one-shot is triggered and the output goes HIGH. That action removes an internal ground by driving Q1 into cut- off, allowing C1 to charge (pin 7). When the charge on C1 nears Vcc, the output of the internal flip-flop is reset, and the output goes back LOW (pin 6). The time constant of C1 and R1 determines the amount of time the output pulse remains HIGH.

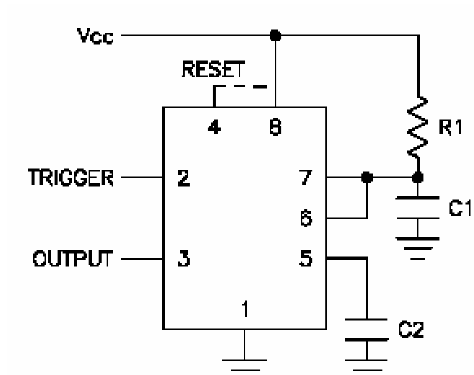


Figure 5. 555 Timer Configured as a Monostable Multivibrator

EXPERIMENT

The purpose of this experiment is to observe the operation of a 555 Timer in the astable and monostable modes. You will select the mode of operation by changing switch positions on the PC card as you observe the timer's output signal. Also, you will change the frequency of the multivibrators by selecting different values of resistance and capacitance.

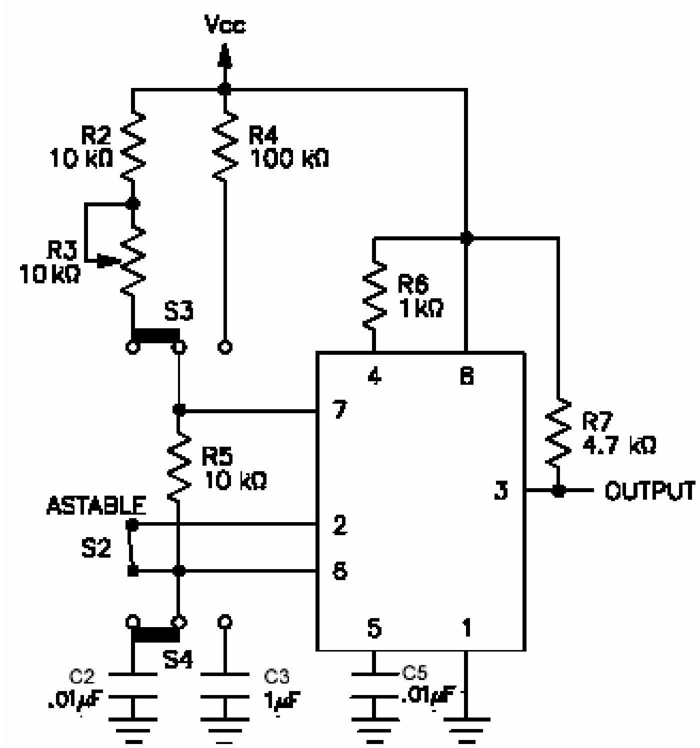


Figure 6. 555 Astable Operation

PREPARATION

Look at experiment card PC130-153. On the right hand side of the card is the 555 Timer. Notice that it is an eight pin DIP IC and that there are test points for each pin, with numbers that correspond to the IC's pin numbers. In this experiment, refer to Figure 2 or the components inside the chip. he five slide switches are used to configure the timer to different modes of operation and to select different values of resistance and capacitance. S1 in the up position supplies an external trigger input (if used) to pin 2 of the timer (negative input of comparator 2). S1 in the down position supplies an external signal to the control voltage input of the timer, pin 5. S2 selects between astable (down) and monostable (up) operation. S3 selects between different resistive values, while S4 selects between different capacitive values. S5, when up, supplies an external sync signal that is applied to the reset input, pin 4. S6 is a push button switch used in the monostable mode to trigger an output pulse.

PROCEDURE

1. Set the POSITIVE and NEGATIVE SUPPLY controls to OFF.
2. Turn the CONSOLE POWER switch to ON.
3. Set the POSITIVE SUPPLY voltage to 5.
4. Carefully insert PC130-153 into the PC1 connectors.
5. Set PC130-153 switches as follows:
   a. S1 to INPUT TRIGGER, up.
   b. S2 to ASTABLE, down
   c. S3 to 20 k, left.
   d. S4 to 0.01, left.
   e. S5 to OUT, down.
6. Place the PC1 DC POWER switch to ON.

The card is now set up for astable multivibrator operation. Refer to Figure 6 and Figure 2. C2 is charged from Vcc through the resistance selected by S3 and R5.

During the time that the capacitor is charging, the output of the timer is HIGH. Once the voltage on pin 6 increases to above the reference, the RS F/F changes states to a LOW output. At this time, due to Q1 turning ON, pin 7 is placed at ground. This causes the charged capacitor to discharge through R5 to pin 7 to ground. Once the voltage on the capacitor decreases to below the reference on pin 2, the RS F/F sets or changes to a HIGH output. The cycle continues as long as power is applied to the circuit.

7. Connect the CH1 probe of the oscilloscope to the OUTPUT test point on the PC130-153 card. The probe will remain on the OUTPUT test point during the entire experiment. Notice that the output is a square wave of a certain frequency. The action of C2 charging and discharging causes the RS F/F in the timer to continually change states. Since the lowest values of resistance and capacitance are used at this point in the experiment, the RC time constant is low, making the frequency high.

Remember, the RC time constant is measured in seconds and is equal to the resistance times the capacitance.

$$\mathbf{TC = R \times C}$$

Also note that the ON and OFF times of the output signal are not the same. In reference to Figure 6, the charge path (ON time) is from Vcc through R2/R3 to R5. The discharge path is only through R5 to pin 7. The discharge path has less resistance; the RC time constant is less. This makes the OFF time less.

8. Rotate R3 CW and CCW and observe the effects on the output signal. You are changing the resistance from 20 k̃ to 30 k̃ for the charge path of C2 (remember to add the value of R2 and R5), which changes the frequency.

Rotating R3 CW increases the resistance, which increases the RC time constant, which decreases the frequency. Check that the frequency does decrease when R3 is rotated CW. Remember, frequency equals one over time:

$$f = \frac{1}{T}$$

9. Place S3 to the 100k position.

Did the frequency increase or decrease? ______________________

10. Place S4 to the 1.0 position.

Did the frequency increase or decrease? ______________________

When the capacitance increases, the RC time constant increases.

One of the advantages of the 555 Timer is that changes in Vcc do not affect the frequency of the circuit. Let's verify that.

11. Place S3 and S4 to the left and place S2 to ASTABLE.
12. While observing the frequency of the output signal with the oscilloscope, set the POSITIVE SUPPLY voltage to 12.

The amplitude of the output signal should have increased, but the frequency should have remained the same.

13. Set the POSITIVE SUPPLY voltage to 15 and observe the frequency of the output signal.

Vcc does not affect the operation of the 555 Timer.

14. Return the test console POSITIVE and NEGATIVE SUPPLY controls to OFF.
15. Turn the CONSOLE POWER switch to OFF.
16. Disconnect all test instruments and carefully remove the PC130-153 card.
17. Return all equipment to its proper storage area.

Lab Session 11B

OBJECTIVE

1. Observe the operation of the 555 Timer in a Monostable mode.

EQUIPMENT REQUIRED

- Nida 130E Test Console
- Nida Series 130 Experiment Card : PC130-153
- Oscilloscope

INTRODUCTION

555 TIMER MONOSTABLE MULTIVIBRATOR OPERATION

Figure A is the schematic diagram of a 555 Timer configured as a monostable multivibrator. The only time the monostable, or one-shot, changes a state is when it receives an input trigger (also refer to Figure 2). When the trigger input goes LOW, the one-shot is triggered and the output goes HIGH. That action removes an internal ground by driving Q1 into cut- off, allowing C1 to charge (pin 7). When the charge on C1 nears Vcc, the output of the internal flip-flop is reset, and the output goes back LOW (pin 6). The time constant of C1 and R1 determines the amount of time the output pulse remains HIGH.

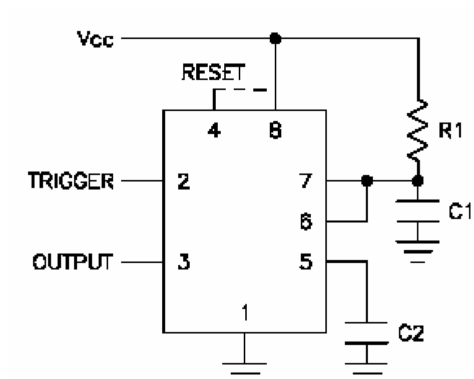


Figure A. 555 Timer Configured as a Monostable Multivibrator

PROCEDURE

1. Set the POSITIVE and NEGATIVE SUPPLY controls to OFF.
2. Turn the CONSOLE POWER switch to ON.
3. Set the POSITIVE SUPPLY voltage to 5.

4. Carefully insert PC130-153 into the PC1 connectors.
5. Set PC130-153 switches as follows:
    a. S1 to INPUT TRIGGER, up.
    b. S2 to MONOSTABLE.
    c. S3 to 20 k, left.
    d. S4 to 0.01, left.
    e. S5 to OUT, down.
6. Place the PC1 DC POWER switch to ON.

The card is now set up for monostable multivibrator operation. Refer to Figure 1 and Figure 2.

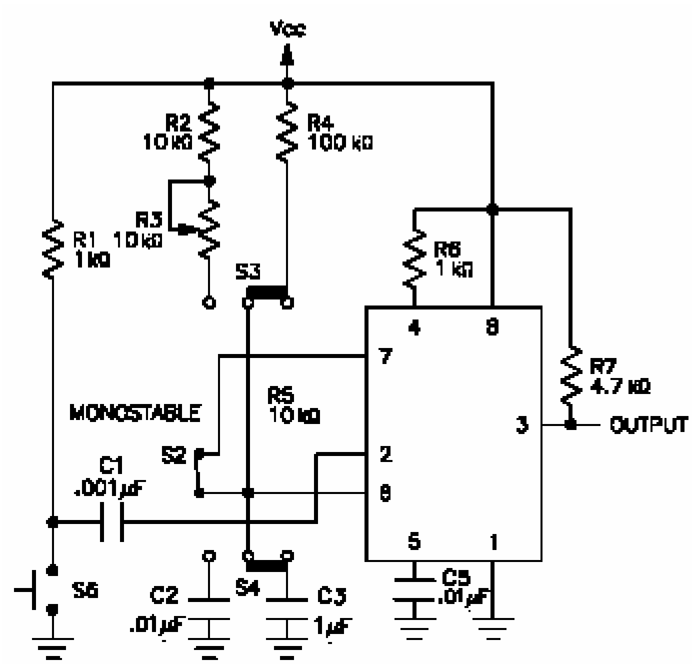


Figure 1. 555 Monostable Operation

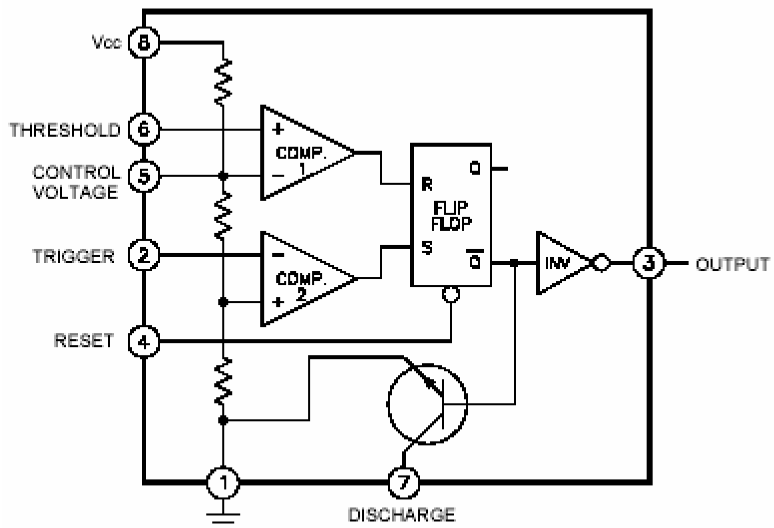


Figure 2. 555 Timer Block Diagram

The output of the flip-flop is LOW or reset. This places a ground on pin 7, grounding pin 6. The timer remains at a LOW output. When S6 is depressed, a pulse is coupled across C1 to the trigger input, which causes the timer to set, HIGH output. The high output removes the ground from pin 7. Once the voltage on pin 6 exceeds the reference, the RS F/F is reset to a LOW output. The timer stays in this condition until another pulse is received from S6 (or an external input pulse). The time that the F/F stays set, HIGH, depends on the RC time constant. A short input pulse is made longer by the action of the multivibrator. 12. Ensure that the oscilloscope is still connected to the OUTPUT test point. Notice the level indicated on the oscilloscope. It is a LOW level.

7. Press and release S6 on PC130-153 while observing the oscilloscope. The LOW level changed to a HIGH level momentarily.
8. Press and hold S6 in.

The HIGH level still was a momentary high. The action of C1 only passes a change in level to the trigger input. Whatever the length of the trigger pulse, the timer only produces a HIGH output for as long as the RC time constant of R4 and C3.

8. Place S3 to the 20k position and S4 to the .01 position.
9. Press and release S6.

Did the length of time that the timer produced a HIGH increase or decrease? ______________________

10. Rotate R3 CW and CCW and change S3 and S4 to different position. Observe the effect on the output signal.

11. Return the test console POSITIVE and NEGATIVE SUPPLY controls to OFF.
12. Turn the CONSOLE POWER switch to OFF.

13. Disconnect all test instruments and carefully remove the PC130-153 card.
14. Return all equipment to its proper storage area.

ANALYSIS

- The 555 Timer is a very versatile circuit that can be configured in different ways by external components.
- The bistable flip-flop (RS F/F) can be changed to an astable and monostable multivibrator.
- RC time constants are used to change the configuration of the timer.
- Variation in Vcc does not affect circuit operation.

SUMMARY

- The 555 integrated circuit is a very stable device that produces accurate time delays or oscillations.
- The output waveform of a 555 Timer is a square wave.
- The 555 Timer can be configured as an astable multivibrator, monostable multivibrator, pulse width modulator, pulse position modulator, or linear ramp generator.
- The frequency of the output waveform of a 555 Timer configured as a multivibrator is determined by the RC time constant of the external capacitor and resistor.

EXERCISES

1. What is the heart of a 555 Timer?
   a. JK flip-flop
   b. D Type flip-flop
   c. Counter
   d. RS flip-flop

2. What is the output waveform of a 555 Timer configured as a multivibrator?
   a. Sine wave
   b. Square wave
   c. Pulses
   d. Triggers

3. What is the most common use of a 555 Timer?
   a. Timing
   b. Multiplication
   c. System reset
   d. None of the above

4. How can a 555 Timer be used to form the basis of many different types of circuits?
   a. Internal connections
   b. Different designs
   c. External connections and components
   d. External components

5. What determines the frequency of a 555 Timer?
   a. External resistors
   b. External connections
   c. RC time constant of external components
   d. Internal connections

6. What is the normal output of a 555 Timer configured as a monostable multivibrator?

   a. HIGH
   b. LOW
   c. Variable
   d. Sine wave

7. The range of timing available from a 555 Timer is from ____________ to ____________ .

   a. seconds to hours
   b. milliseconds to hours
   c. microseconds to days
   d. microseconds to hours

8. The output current of a 555 Timer is 200 mA so that the device can drive ____________ and ____________ .

   a. relays and coils
   b. relays and other circuits
   c. coils and lamps
   d. relays and lamps

9. Vcc for a 555 Timer can vary from ____________ to ____________

   a. 5 VDC to 10 VDC
   b. 5 VDC to 15 VDC
   c. 5 VDC to 12 VDC
   d. 5 VDC to 18 VDC

10. A 555 Timer is constructed from ____________ , ____________ , and a ____________ .

    a. comparator, 2 transistors, RS flip-flop
    b. comparator, 2 RS flip-flops, transistor
    c. 2 comparators, RS flip-flop, transistor
    d. none of the above