EE100B
Experiment 6

The Design of Waveform Generators

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Objective

To familiarize with some quite general ideas concerning the generation of waveforms using a combination of fast-acting positive feedback and delayed negative feedback.

Equipment

Op-amp (741), 2 diodes (1N914), resistors (10kΩ and 3 100kΩ) 2 10nF capacitors, function generator, oscilloscope, digital multimeter, DC power supply, breadboard

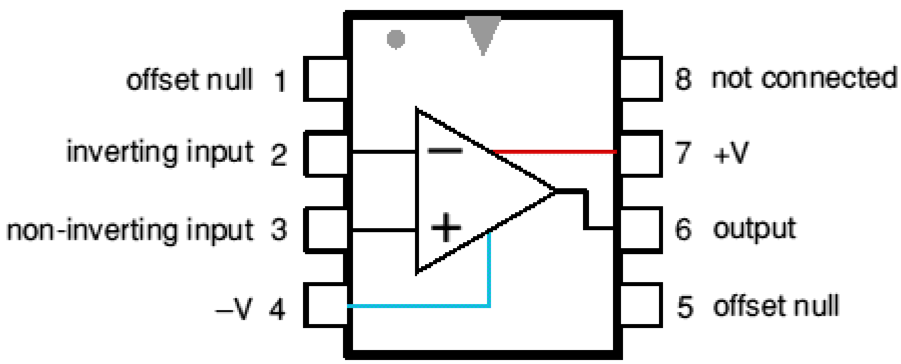

Figure L6.1 741Op-Amp Pin Connections

Prelab

Read the sections of your textbook relevant to this laboratory session.

The Schmitt Trigger

1. Non-Inverting Operation
   For the circuit shown in Figure L6.2 adjusted for ±10V output and with node A grounded, sketch and label the transfer characteristic which applies from node D to node C.

2. Inverting Operation
   For the circuit shown in Figure L6.2 adjusted for ±10V output and with node D grounded, sketch and label the transfer characteristic which applies from node A to node C.

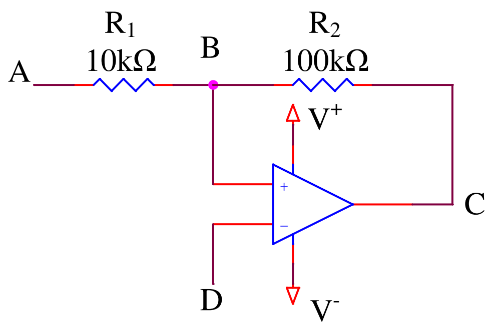

Figure L6.2 A Versatile Schmitt-Trigger Topology

<u>A Square Wave Oscillator</u>

For the circuit shown in Figure L6.3 operating with output levels of ±10V, a design providing a nearly ideal triangle wave at node D is required. For what value of R_1 will the square wave frequency be decreased by 10%?

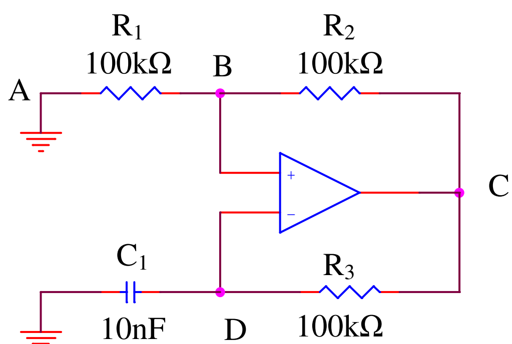

Figure L6.3 A Square-Wave Oscillator, or Astable Multivibrator

<u>A Monostable Topology</u>

For the circuit shown in Figure L6.4, estimate the voltage at node E in the stable state, assuming that the voltage drop of both diodes is to be 0.7V and the output levels are to be ±10V. By what amount must the input at F fall to trigger the monostable oscillator? For the circuit shown in Figure L6.4 what is the effect of removing R_1?

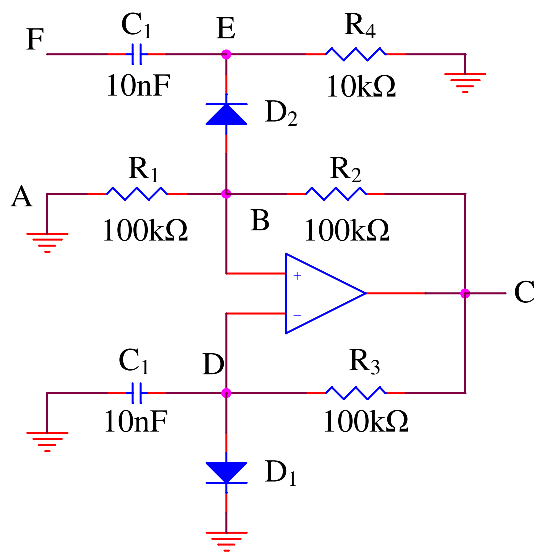

Figure L6.4 A Monostable Multivibrator

Laboratory Procedure

<u>The Schmitt Trigger</u>

Figure L6.2 shows a basic element which recurs in the circuits to follow. It is the positive-feedback Schmitt-Trigger Bistable vibrator. It is operated typically with either of nodes A or D as input, while the other is connected to a reference voltage, often ground. Because of positive feedback, the output voltage (v_C) is stable at one of two limiting values which depend on the choice of power supplies V^+ and V^-, and amplifier saturation characteristics. Toward the latter part of this exploration we will consider one particular approach to make the output independent of supply voltage and op-amp variability.

1. Non-Inverting Operation
   Assemble the circuit as shown in Figure L6.2 with node D grounded and node A connected to a waveform generator. Adjust the power supplies to about ±12V. Externally trigger the oscilloscope from the generator's trigger-source output. With the function generator providing a 5 V_{pp} triangle wave at 1 kHz to node A, display the waveforms at nodes A and C, noting the limiting voltage levels at node C. Adjust the supply voltages (V^+ and V^-) so that the limiting voltages at node C are close to ±10V. Displaying the waveforms at nodes A and C, note carefully the voltage values at which interesting waveform changes occur. Repeat with the waveforms at nodes A and B. Estimate the rise and fall times of the signals at nodes C and B.
   Consider the operation of this circuit by sketching its transfer characteristic (v_C versus v_A). Note the hysteresis region, its width, and the simple relationship it bears to the limiting voltages and the resistors (R_1, R_2).
2. Inverting Operation
   Assemble the circuit as shown in Figure L6.2 with node A grounded and node D connected to a waveform generator. Adjust the supplies initially to ±12V. With the generator providing a 3 V_{pp} triangle wave at 1 kHz to node D, and observing node C, adjust the supply voltages (V^+ and V^-) so that the limiting voltages at node C are close to ±10V. With the oscilloscope triggered directly from a fixed-voltage generator output,

and displaying both nodes D and C, adjust the amplitude of the triangle wave input, so as to identify the input triggering levels, the relative timing of the output, and the minimum input signal for which node C reverses state. Shunt R_1 by an additional 10kΩ resistor, first measuring nodes D and C and then nodes D and B, to identify triggering levels and the input signal amplitude below which operation ceases.

Consider the operation of the circuit in relationship to the version explored earlier for the non-inverting case, noting the relative differences in polarity, input resistance, and the simplicity with which thresholds can be calculated. As we shall see, next, the signal-inverting property can be of special importance.

A Square-Wave Oscillator

In general, one approach to creating an oscillator is to use a positive-feedback-based bistable element with delayed negative feedback. A simple implementation of this idea is shown in Figure L6.3. Here, the connections of the amplifier with R_1 and R_2 form an inverting bistable whose output and input signals are of reversed polarity with input going high (or low) (beyond the corresponding threshold) causing the output to go low (or high), respectively. Components R_3 and C_1 form a simple non-inverting delay element, whose output D follows its input C after a delay related to the time constant R_3C_1. The combination is a circuit which reverses its state periodically, forming a square-wave oscillator.

Assemble the circuit as shown in Figure L6.3. To make the interpretation of your measurements somewhat easier, you may find it useful to adjust the supply voltages so that the signal levels at node C are ±10V. Connect the oscilloscope probes to nodes C and D, noting the relative voltage levels, time intervals and frequency. Observe nodes D and B in order to verify that the output state reverses when the capacitor voltage reaches one of the bistable thresholds. While observing nodes C and D, shunt C_1 with a capacitor of equal value, noting the changes in time intervals and frequency, but not of waveform. With the additional capacitor removed, shunt R_1 by a 10kΩ resistor, noting changes in waveshape at node D and the corresponding frequency.

Consider the ease with which a square wave can be generated using this idea. Note that when the bistable switching threshold is made quite small, a reasonable triangle wave is also available at node D. A low-impedance triangle wave of amplitude equal to that of the square wave can be created using a second op-amp connected as an amplifying buffer with virtually the same values of R_1 and R_2 as employed by the oscillator.

A Monostable Topology

In the circuit shown in Figure L6.3, if a diode is connected from node D to ground, (say with cathode on ground), node D is clamped at +0.7V or so, and thereby prevented from reaching the bistable's upper threshold. As a result, circuit operation stops with node C at its high value (say +10V) and D at 0.7V. Thus, the circuit is monostable.

To put it in the active region ever again requires some additional external input. Such an arrangement is shown in Figure L6.4, where D is the diode just described. Components D_2, C_2 and R_4 allow a signal at node F to control the upper threshold (the voltage at node B) of the bistable.

Assemble the circuit as shown in Figure L6.4. Apply a square wave to node F of 2 V_{pp} amplitude at 100 Hz. Display nodes F and C on the oscilloscope, noting the relative timing. Adjust the supplies to establish the limits of the output signal at node C at ±10V. With node C as a reference, examine nodes D, B, E, F in turn, noting first the effect and then its cause (as an exploratory reversal of the usual cause-effect analysis). Note the relative voltage levels and timing of all the waveforms.

Displaying the signals at nodes F and B, lower the square-wave input amplitude until normal operation just ceases. Note the minimum signal required. At an input voltage barely above the triggering threshold, examine nodes E, B, D in turn, carefully noting the relative activity just at the triggering point. Adjusting the input amplitude intermittently around the threshold is likely to aid in your understanding.

While examining nodes B and D, raise the input signal to a large value, in an attempt to identify any effect of very large input signals.

Consider the normal operation at relatively low repetition rates: the range of triggering signal amplitudes, the roles of D_1 and D_2, the effective time constants at nodes D and E, and the role of C_2.