Oscillators



• Amplifiers are based on feedback where output voltage is added to the input.



• The effective gain *A* is:

$$A = \frac{v_{out}}{v_{in}} = \frac{A_0}{(1 - A_0 \alpha)}$$

• If αA_0 is negative there is a normal amplifier:

$$A = \frac{A_0}{(1 - A_0 \alpha)} < A_0$$

• If αA_0 is near 1:

$$A = \frac{A_0}{(1 - A_0 \alpha)} \Longrightarrow \infty$$

This will give oscillations

There are also oscillations for $\alpha A_0 > 1$.

Signal Phase _____**/**///____**>**

- Positive feedback must be in phase to compensate for energy lost on each oscillation.
- The low pass filter provides a phase shift that depends on the frequency.



• The phase can be expressed in terms of the complex impedance.

$$B = \frac{1}{1 + \omega^2 R^2 C^2}$$

$$jC = \frac{-j\omega RC}{1 + \omega^2 R^2 C^2}$$

$$\phi = \operatorname{atan} \frac{-\omega RC}{1} = \operatorname{atan} (-\omega RC)$$

• The phase depends on the frequency: At high frequency, $\phi \rightarrow -90$ At $\omega = 1/RC$, $\phi = -45$

At low frequency, $\phi \rightarrow 0$

Wien Bridge Oscillator

- The Wien bridge oscillator uses positive feedback to get a phase shift on an RC filter.
- The positive feedback can be calculated from the RC filters.

$$Z_{RCser} = 1/(j\omega C) + R = \frac{1+j\omega RC}{j\omega C}$$
$$Z_{RCpar} = \frac{R/j\omega C}{1/(j\omega C) + R} = \frac{R}{1+j\omega RC}$$



• The RC networks provide a voltage divider for the non-inverting input.

$$v_{non} = \left[\frac{Z_{RCpar}}{Z_{RCpar} + Z_{RCser}}\right] v_{out} = \left[\frac{1}{j\omega RC + 1/(j\omega RC) + 3}\right] v_{out}$$

- The inverting input must be equal to the non-inverting input so the variable resistor voltage divider should be set to 1/3.
- Matching terms in the complex expression is called phase cancellation.

$$0 = j\omega RC + 1/(j\omega RC)$$

$$\omega = 1/RC$$

• The frequency ω is the point of stable oscillations.

Self-Regulating Feedback

- It is very difficult to get the oscillator feedback set to exactly 1/3.
- The Wien bridge oscillator could be better with a resistance on the inverting input that varies with current, eg. a lamp.
- Another solution is to use an FET as the variable resistor. The RC delay on the signal to the FET gate makes the circuit resistance vary slowly compared to the frequency of oscillation.





LC Oscillators



• The Colpitts oscillator uses an LC resonance to establish the oscillation.



The inverting input is a parallel LC circuit (impedance divider) and the positive feedback is through the capacitor.

• The Hartley oscillator also uses an LC resonance to establish the oscillation.



Crystal Oscillators

• A quartz crystal converts strain into voltage through piezoelectricity: The schematic symbol for a crystal:



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• There are natural crystal oscillations equivalent to an RLC circuit.



• The crystal oscillator forms a tuned LC-feedback for the op-amp.



• The crystal is usually only marked with the characteristic frequency.

Comparator

• A comparator returns one of two values based on whether the input is greater or less than a reference value.

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• An op-amp can function directly as an analog comparator.



The logic states are $v_{out} = V_{CC}$ if $v_{in} > V_{ref}$; $v_{out} = V_{EE}$ if $v_{in} < V_{ref}$.

• Low-battery indicator



 V_{bb} is the value to be tested, V_{CC} supplies power to the tester.

LABORATORY ELECTRONICS II



- The Schmitt trigger is a circuit with binary output that has thresholds at two different voltages depending on the present state of the output.
- This combines analog elements with binary logic.



• The non-inverting input of the op-amp has a threshold which solely based on the three resistors and V_{ref} and v_{out} .

$$v_{th} = V_{ref} - i_2 R_2 = v_{out} - i_3 R_3 = i_1 R_1 = (i_2 + i_3) R_1$$
$$v_{th} \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = \frac{V_{ref}}{R_2} + \frac{v_{out}}{R_3}$$

For equal resistors and 5 V supply, v_{th} =1.67 V or 3.33 V for v_{out} = 0 V or 5 V respectively.



• The Schmitt trigger circuit has one threshold when approaching from a low voltage state and a different one when approaching from a high voltage state.



- The effect of having different thresholds for different directions is called *hysteresis*.
- A plot of the input versus output shows the hysteresis diagram.



Relaxation Oscillator

- The relaxation oscillator uses an RC network on the inverting input.
- A current flowing through R_f can charge or discharge the capacitor *C* with a time constant $t = R_f C$.
- The threshold for the output shifts due to the hysteresis of the amplifier.



• The output voltage is set at either $+V_{CC}$ or $-V_{CC}$ depending on the relative values of V_{cap} and V_{thr} , and the period depends on V_{thr}/V_{out} .



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Triangle-Wave Oscillator



• The relaxation oscillator can be modified to charge the capacitor with a constant current.



The JFET pair is Q_1 and Q_2 . When the gate is more positive the JFET conducts, if the gate is more negative it acts as a current source.

When $V_{out} = -V_{CC}$: Q_1 conducts and Q_2 provides constant current.

When $V_{out} = +V_{CC}$: Q_2 conducts and Q_1 provides constant current.

Triangle Timing



• The period is

$$T = \frac{4\lambda C V_{CC}}{I}$$

• The triangle wave is not from V_{out} but instead from V_{cap} .

Monostable Multivibrator

- The monostable multivibrator, also called a *one-shot*, is a device with two output states that has one stable state and another of fixed duration.
- An op-amp one-shot can be made from a relaxation oscillator.



- Here the negative feedback capacitor is shorted by a diode, $V_C < 0.6 V_c$.
- When V_{out} is low the capacitor will discharge, but when V_{out} is high the capacitor will only charge to 0.6 V.

$$\frac{V_{out}R_1}{R_1 + R_2} = V_{out} + (V_D - V_{out})e^{-t/RC}$$

$$t = RC \log \left[\frac{(V_{out} - V_D)(R_1 + R_2)}{V_{out}R_2} \right]$$



- Dead time is the time when a device cannot function normally.
- The recovery time as the capacitor is charging towards 0.6 V a new trigger would need to be sufficiently negative to permit refiring.
- With the resistor divider, this is not generally possible and no trigger is accepted during this period.

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Inverter One-Shot



- The input pulse is altered by the high-pass filter.
- The falling edge of the input pulse has no effect, but the rising edge produces a pulse into the inverter that crosses the threshold for a time proportional to *RC*.





 $t = RC\log 2 = 0.693RC$

Astable Multivibrator



• The output of a monostable multivibrator can feed back to retrigger another one-shot cycle.

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When $V_{out} = +5$, V_C is charged towards ground from V_2 . As the input V_1 drops below the logic threshold, $V_2 = +5$ and $V_{out} = 0$. When $V_{out} = 0$, V_C is charged towards +5 from V_2 .

• The system oscillates between the two states.

 $R_1 \cong 10R_2$ $f \approx \frac{1}{R_2C}$



• Making a one-shot from gates leaves a design that depends on the individual component characteristics.

• Integrated one-shots avoid component variations, and require only the external resistor and capacitor to set *RC*.



- A, B and X can trigger the one-shot, A with a falling edge, B and X with rising edges. X also acts as a reset for Q.
- R and C set the time constant for the output pulse. As long as an input triggers the circuit the output will continue to *retrigger*.

555 Timer

- One of the most important multivibrators is the 555 timer.
- The 555 uses two internal thresholds.
- There are three external points, one is <u>BAL</u> set by the external RC network, one by an external pulse, and one is used to discharge the capacitor.
- In this configuration the 555 timer acts as a one-shot.
- The input pulse starts the charging capacitor.
- When the threshold is reached the capacitor discharges.



• The output pulse length is $T = RC\ln 3 = 1.1RC$.



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555 as an Astable Multivibrator



• The output pulse length is

 $T = (R_1 + R_2)C\ln 2 + R_2C\ln 2 = 0.693(R_1 + 2R_2)C.$

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Duty Cycle



- The ratio of the high part of the cycle to the period is the duty cycle.
- For the 555 timer, duty cycle = $(R_1 + R_2) / (R_1 + 2R_2)$.
- A duty cycle can be evened out by putting the output into a divide by two latch.
- A diode can make a low duty cycle 555 circuit.



- The 555 is set up as a monostable with $T_l = 0.693R_1C$. When the output is low the diode is off and the discharging is through the 555. When the output is high the diode conducts and the charging is through R_2 .
- For $R_2 \ll R_1$ there will be short pulses at the period T_l .

Sawtooth Oscillator

- A constant current creates a linear change on the capacitor.
- There will be a triangle wave while charging but an immediate discharge.
- This circuit uses the 555 timer chip as an oscillator.



• The pnp transistor forms a constant current source with

$$I_C = \left\{ V_{CC} - \left[V_{CC} \left(\frac{R_2}{R_1 + R_2} \right) + V_{BE} \right] \right\} / R_E$$

- The capacitor charges to 2/3 V_{CC} then immediately discharges to 1/3 $V_{CC.}$

Sawtooth Wave



• The period is

$$T = \frac{CV_{CC}}{3I_C}$$

• A buffer at V_{cap} is needed to drive other circuits.