ECTE313
Electronics Part II

Week 4

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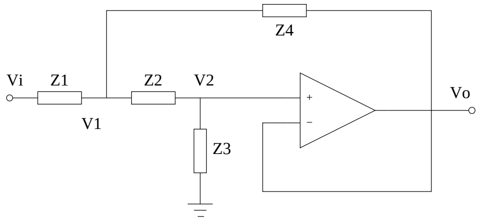
Notes:

Sinusoidal Oscillators

- This week we will briefly wrap up the work on second-order filter realisations by looking at several Sallen and Key single-amplifier filters;
- We will then look at a closely related area - sinusoidal oscillator circuits:
  - Oscillator model
  - Oscillation conditions
  - Example circuits

Notes: This week's material is closely based on Sedra and Smith, 5th Edition, Section 13.1 and 13.2, or 4th Edition, Section 12.1 and 12.2.

Sallen and Key Realisations



- Sallen and Key realisations amongst the the most popular single-amplifier biquads;
- Simple and easy to design - you've already seen one for implementing a LPF in Tutorial 1;

$$H(s) = \frac{Z_3 Z_4}{Z_2 Z_4 + Z_3 Z_4 + Z_1 Z_2 + Z_1 Z_2 + Z_1 Z_4}$$

Notes:

Sallen and Key Realisations

- If we set $Z_1 = R_1$, $Z_2 = R_2$, $Z_3 = \frac{1}{sC_1}$, $Z_4 = \frac{1}{sC_2}$, we have a LPF:

$$H(s) = \frac{1}{1 + (R_1 + R_2)C_1 s + R_1 R_2 C_1 C_2 s^2}$$

- Swapping R_n for C_n, we have an HPF:

$$H(s) = \frac{R_1 R_2 C_1 C_2 s^2}{1 + (C_1 + C_2)R_2 s + R_1 R_2 C_1 C_2 s^2}$$

Notes:

Sallen and Key Realisations

- Sallen and Key bandpass filters are a little more complex, requiring an extra resistor.
- Band-reject S&K filters require an extra resistor and an extra capacitor.
- You can also add an integrator to the HPF or a differentiator to the LPF to create a BPF.

Notes: There are many other families of single-amplfiier biquads. However, the Sallen and Key is the design of choice for most applications where the filter specifications are not too tight.

Sinusoidal Oscillators

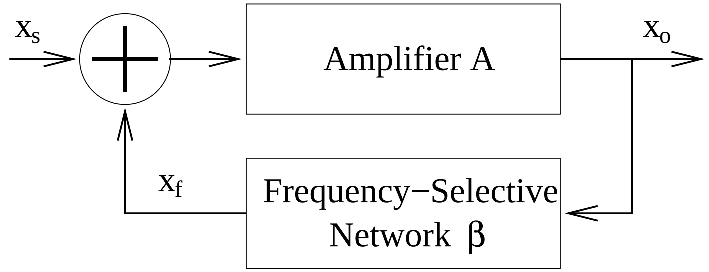


Figure 1: Basic Oscillator Model

- Oscillation is achieved by *positive feedback*

Notes:

Sinusoidal Oscillators

- The transfer function is given by

$$H(s) = \frac{A(s)}{1 - A(s)\beta(s)} \quad (1)$$

- *Loop Gain* is defined as $L(s) = A(s)\beta(s)$. Thus the poles of the system are found by solving $1 - L(s) = 0$.
- Thus when the loop gain is unity, we have infinite gain - i.e. nonzero output for zero input
- In other words: oscillation!

Notes: x_s is not required in a real oscillator - it helps with the analysis.

The Barkhausen Criterion

- The criterion for oscillation is

$$L(j\omega_0) = A(j\omega_0)\beta(j\omega_0) = 1 \quad (2)$$

- So the overall loop gain should have unity magnitude and no phase shift at ω_0. This is the *Barkhausen criterion*.
- Frequency stability is determined by the dependence of $L(j\omega)$ on frequency - if the Barkhausen criterion is satisfied only over a narrow range of frequencies, the output signal will be of high purity.

Notes:

Practical Oscillators

- In practice it is not possible to achieve or maintain the Barkhausen criterion exactly with real components
- If loop gain is
  - Greater than 1, oscillations will grow to the point of saturation
  - Less than 1, oscillations will decay to zero
- To actually kick-start oscillation we would actually like $L(\omega_0) > 1$ at the beginning, but have it reduce to 1 as the amplitude approaches the desired value.

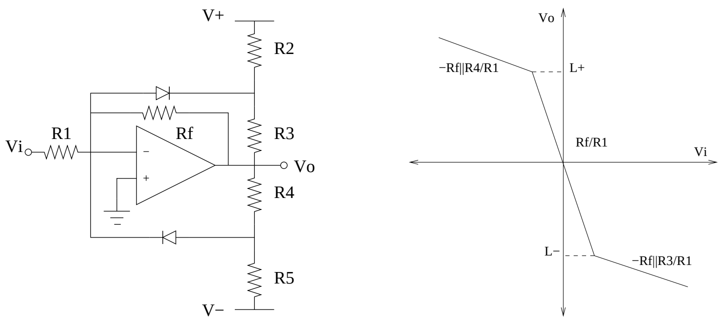
Notes:

Non-Linear Gain Control

- Gain control is achieved in one of two ways:
  - Some form of voltage-controlled resistance (such as a FET or diode)
  - Some form of non-linear *limiter* - an amplifier whose gain is less at greater amplitudes.

Notes:

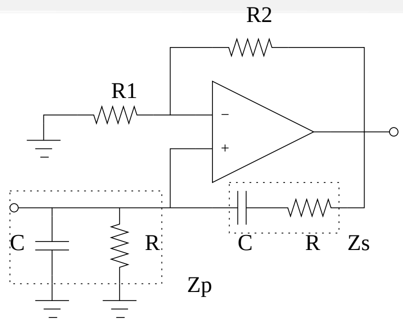
Non-Linear Gain Limiter



- $L_+ = V\frac{R_4}{R_5} + V_D\left(1 + \frac{R_4}{R_5}\right)$
- $L_- = -V\frac{R_3}{R_2} - V_D\left(1 + \frac{R_3}{R_2}\right)$

Notes:

Wein-Bridge Oscillator



- A simple oscillator based on a non-inverting amplifier configuration, with reactive components providing positive feedback to the non-inverting input.

Notes:

Wein-Bridge Oscillator

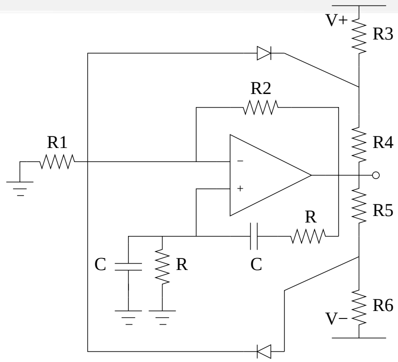
- $L(s) = \left(1 + \frac{R_2}{R_1}\right) \frac{Z_p}{Z_p + Z_s}$
- Substituting for Z_p and Z_s, and setting $s = j\omega$, we have

$$L(j\omega) = \frac{1 + \frac{R_2}{R_1}}{3 + j\omega RC + \frac{1}{j\omega RC}}$$

- We want the loop phase to be zero at ω_0, thus $\mathrm{Im}\{L(j\omega_0)\} = 0$ - hence $\omega_0 RC = \frac{1}{\omega_0 RC}$ which means that $\omega_0 = \frac{1}{RC}$. Similarly, $|L(j\omega_0| = 1$, which leads to $\frac{R_2}{R_1} = 2$.

Notes: In case it isn't obvious, what we have here is a non-inverting amplifier with gain $1 + \frac{R_2}{R_1}$. The input, however, is connected to the output via a frequency-selective voltage divider network with gain $\frac{Z_p}{Z_p+Z_s}$. Thus the closed-loop gain is the product of these two expressions.

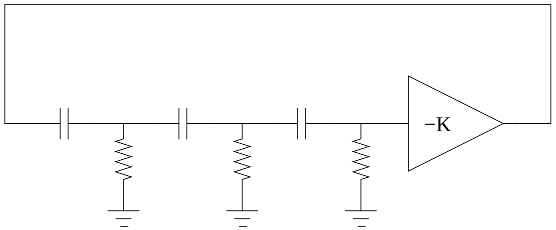
Wein-Bridge Oscillator



- Set $\frac{R_2}{R_1} > 2$ to ensure that oscillation will start
- With the limiter as shown above, the loop gain reduces once $|H(s)|$ is |sufficiently high.

Notes: The output voltage limits are determined by a few careful observations about this circuit. Assuming the limiter is working and the output is at its clamped maximum, the voltage at the inverting input will be $\frac{R_1}{R_1+R_2}V_o$ (voltage divider). The bottom diode will *just* start conducting (i.e. a negligable amount of current will flow through the diode, so this current can be ignored in nodal analysis) and the voltage at the anode of the diode is about 0.7 V above the voltage at the inverting input. Solving the nodal equation at the anode of the lower diode, we can write that $\frac{V_{anode} - -V}{R_6} = \frac{V_o - V_{anode}}{R_5}$. Solving these equations simultaneously results in $V_o = \frac{V\frac{R_5}{R_5+R_6} + 0.7}{\frac{R_6}{R_5+R_6} - \frac{R_1}{R_1+R_2}}$. The negative peak is equal in magnitude.

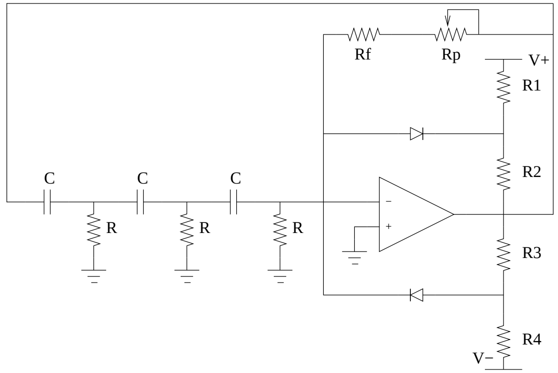
Phase-Shift Oscillator



- Based around an RC ladder network which results in a 180 degree phase shift
- This, plus an inverting amplifier, can give a zero phase shift for certain frequencies
- K is chosen such that at ω_0 it slightly exceeds the reciprocal of the ladder circuit 'gain'.

Notes:

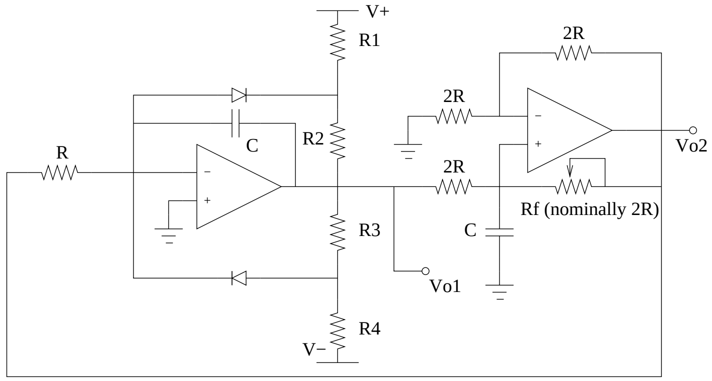
Phase-Shift Oscillator



- Loop gain at $s = j\omega$ is $\frac{\omega^2 C^2 R(R_f + R_p)}{4 + j(3\omega RC - \frac{1}{\omega RC})}$
- $\omega_0 = \frac{1}{\sqrt{3}RC}$, minimum $R_f + R_p = \frac{4}{\omega^2 RC^2}$

Notes:

Quadrature Oscillator



- Based on the two-integrator loop active filter with poles moved to the RH side of the plane

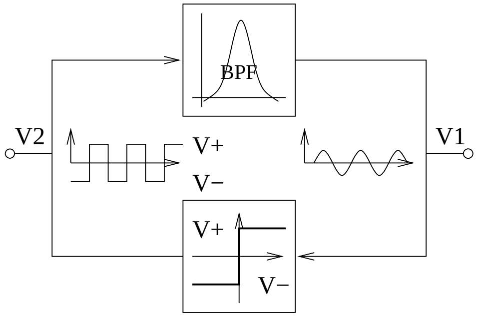
Quadrature Oscillator

- The left-hand amplifier is a clamped Miller integrator
- The right-hand amplifier is a non-inverting integrator
- The feedback resistor in the right-hand integrator should be less than 2R to ensure oscillation will start;
- The most-sinusoidal output may be obtained from V_o.
- Oscillation will occur at $\omega_0 = \frac{1}{RC}$.

Notes:

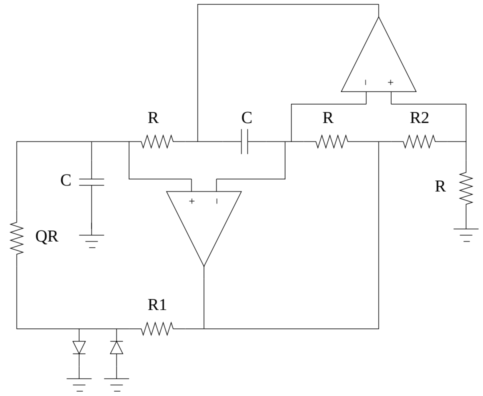
Notes: This circuit is widely used in communications systems where it is useful to have two sinusoids which are 90 degrees out of phase (e.g. sine and cosine). In this case, V_{o2} will give a less-sinusoidal output as compared with V_{o1}. Further improvements in wave shape may be obtained with additional filtering stages.

Active-Filter Tuned Oscillator



- The last major class of oscillators which we will consider;
- Essentially a bandpass filter with a comparator in positive feedback mode

Active-Filter Tuned Oscillator



- This one is based on an Antoniou inductor-replacement, in band-pass mode.
- Again, $\omega_0 = \frac{1}{RC}$

Notes: This architecture results in an excellent sinusoidal signal with a square wave output as an added bonus.

Notes: All of the oscillators dealt with thus far are for frequencies up to about 1 MHz. For higher frequences, you can't avoid inductors, and you will find it progressively more difficult to find operation amplifiers that behave like ideal devices - generally BJTs or MOSFETs are used as the active circuit element. We will return to the subject of RF oscillators later in the course.