Power Electronics

Simulation Exercise# 2

Design of an Analog Modulator for an H-Bridge dc-dc converter

PWM Modulator

Goal

This exercise aims at providing an understanding about the modulation process in a dc-dc converter where pulse width modulated (PWM) signal controls the gate of the switching transistor.

The modulation consists mainly of a triangle wave generator stage and a comparator stage; the triangular wave is basically the carrier wave of desired switching frequency, while the comparator compares the carrier wave to a pre-determined reference voltage in order to produce the desired PWM signal.

Triangle wave generator

The triangle wave generator shown in Figure 1 below consists of a Schmitt trigger, an amplifier circuit with a resistive feedback that is positively fed; and an integrator, an amplifier circuit with a capacitive feedback that is negatively fed.

The output of the Schmitt trigger can only assume two discrete levels, corresponding to its positive and negative supply voltages (approximately). The switching between these two states occurs at two discrete input signal levels. The integrator acts upon the output signal of the Schmitt trigger. The integrator output performs a ramp function as the integrator's input signal is piece-wise constant. By feeding back the ramp signal to the Schmitt trigger, the Schmitt trigger switching is generated upon the magnitude of the ramp signal. In this way the triangular wave is created.
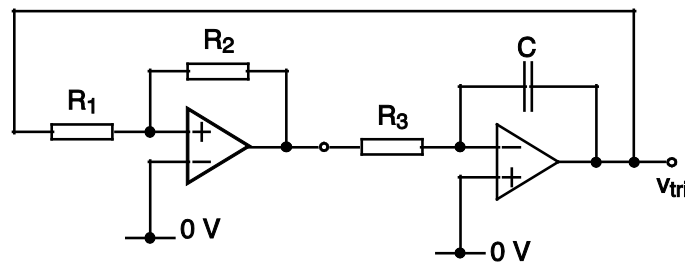
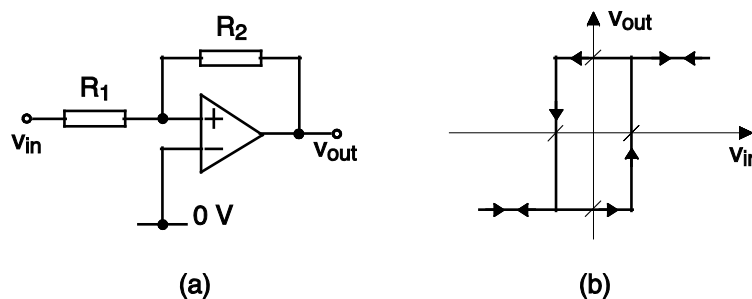**Figure 1**   The triangle wave generator.

Figure 2   (a) The Schmitt trigger. (b) Schmitt trigger input-output characteristic.

For the Schmitt trigger in Figure 2(a) the following derivation is valid:

Considering very high input impedance of the op-amp, the potential of the op-amp's positive input terminal, v_+, is written:

$$v_+ = v_{in} - \frac{v_{in} - v_{out}}{R_1 + R_2} \cdot R_1 = \frac{R_2}{R_1 + R_2} \cdot v_{in} + \frac{R_1}{R_1 + R_2} \cdot v_{out}$$

To find out the input voltage (v_{in}) when the Schmitt trigger output switches from high to low (negative flank), the following relationships are established:

$$v_+ > 0 \quad \Rightarrow \quad v_{out} = +V_{CC}$$

$$\frac{R_2}{R_1 + R_2} \cdot v_{in} + \frac{R_1}{R_1 + R_2} \cdot \left(+V_{CC}\right) = 0 \quad \Rightarrow \quad v_{in} = -\frac{R_1}{R_2} \cdot V_{CC}$$

On the contrary, to calculate the input voltage when the Schmitt trigger switches from low to high (positive flank) output level

$$v_+ < 0 \quad \Rightarrow \quad v_{out} = -V_{CC}$$

$$\frac{R_2}{R_1 + R_2} \cdot v_{in} + \frac{R_1}{R_1 + R_2} \cdot \left(-V_{CC}\right) = 0 \quad \Rightarrow \quad v_{in} = \frac{R_1}{R_2} \cdot V_{CC}$$

These calculations give the input-output characteristics of the Schmitt trigger; see Figure 2 (b). From the figure it is seen that the Schmitt trigger works as a relay with hysteresis.

In Figure 3 below, the integrator of the triangle wave generator is shown.
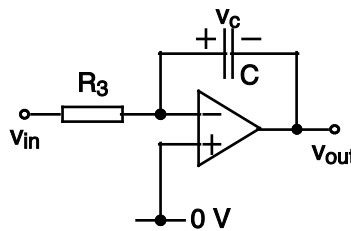
Figure 3   The integrator of the triangle wave generator.

The current through the resistor R_3 and capacitor C, i.e. the integrator current denoted i, is written

$$i = \frac{v_{in} - 0}{R_3} = C \cdot \frac{dv_C}{dt} = C \cdot \frac{d}{dt}\left(-v_{out}\right) = -C \cdot \frac{dv_{out}}{dt} \quad \Rightarrow$$

$$\frac{dv_{out}}{dt} = -\frac{1}{R_3 \cdot C} \cdot v_{in} \quad \Rightarrow \quad v_{out}(t) - v_{out}(t_0) = -\frac{1}{R_3 \cdot C} \cdot \int_{t_0}^{t} v_{in}(\tau) \cdot d\tau$$

Note that the input signal is a square wave which gives

$$v_{out}(t) - v_{out}(t_0) = -\frac{1}{R_3 \cdot C} \cdot v_{in}(t_{0+}) \cdot (t - t_0)$$

The expressions for the Schmitt trigger and the integrator **together** gives that the integrator input and output signals which appear in Figure 4 below.
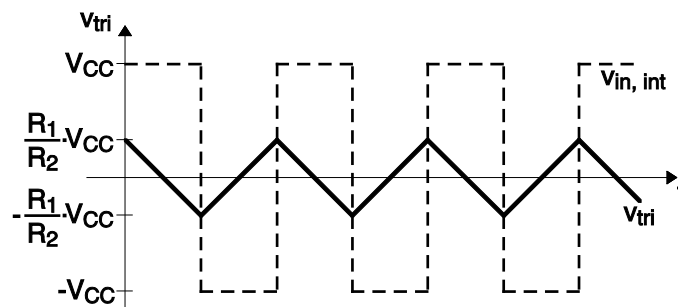
Figure 4   Input and output signal of the integrator.

The Task

1. From the analysis above, and knowing that the triangular wave has a peak amplitude of $\frac{R_1}{R_2} \cdot V_{cc}$, develop an expression for the carrier wave frequency in terms of R_1, R_2, R_3 and C.
2. Using LTspice software design a triangle wave generator for a carrier frequency of 5 kHz. You have access to resistors from 1kΩ up to 30 kΩ and capacitors from 1 nF to 90 nF. You may use the Op-amp LT1058 from the "Opamps" library. Two zener diodes of type 1N750 will be needed to stabilize the voltage level between the Schmitt trigger and the integrator parts.
3. Once you designed and created the triangle wave generator, use your design in the file assignment_2.asc attached to replace the encircled carrier wave generator and more importantly to expand the half-bridge into a full-bridge circuit.

Hand in a group report motivating your solution along with a copy of your (*.asc) file to fadi.abdallah@iea.lth.se no later than February 21st, 2014 @ 17:00 hr.