roel arits electronics hobby shack

Gyrators (especially simulated inductors)

Introduction

Help, i need a huge inductor, but i don't have space or money for it !

If you are in that situation, then a gyrator can probably help you out.

if you need that huge inductor for temporary energy storage in switched power supply applications, a gyrator will not help you out.

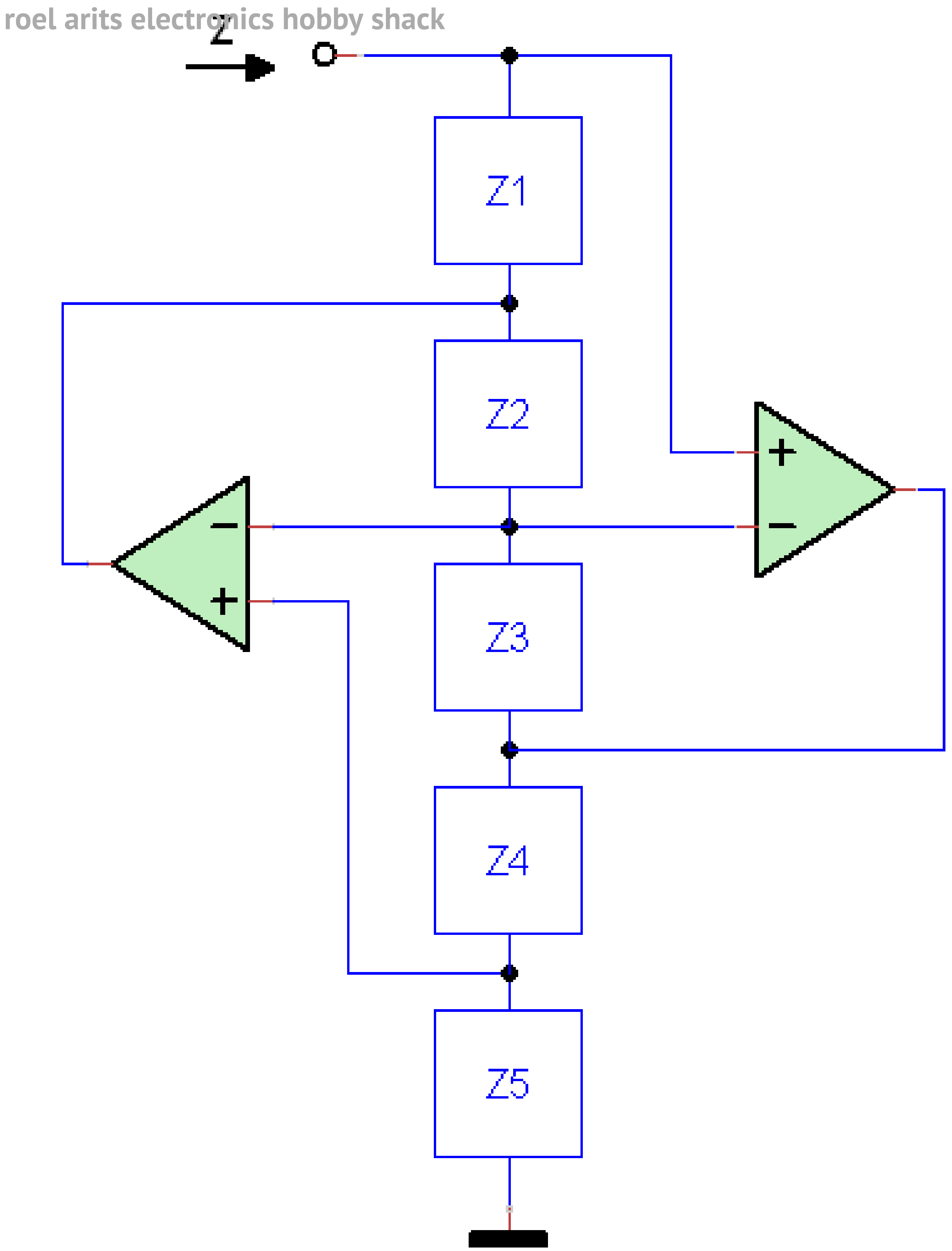
This is because a gyrator can not emulate the magnetic field build-up of an inductor. It only emulates the voltage/current relation (thus impedance) of an inductor.

Gyrators are special circuits that transform an impedance into another (mostly inverse) type of impedance. Gyrators are mostly used to simulate a large inductor using a 'normal' value capacitor. In audio filters such as equalisers, you often find gyrators in the bandpass filter sections, where LC filters are needed that operate in the audio frequency range down to f.e. 10Hz. An LC filter with a resonance frequency of 10Hz would require a large inductor with a value close to 1 Henry. Here a gyrator is an ideal solution, because it does not only transform an capacitive impedance into an inductive impedance but meanwhile also multiplies the capacitive impedance. So with a 'normal' value capacitor, we can create a large inductance.

This is a cost-effective solution in many applications where filtering at relative low frequencies is required. Another benefit of a gyrator is that a bulky inductor would pick up all kind of electro-magnetic interference.

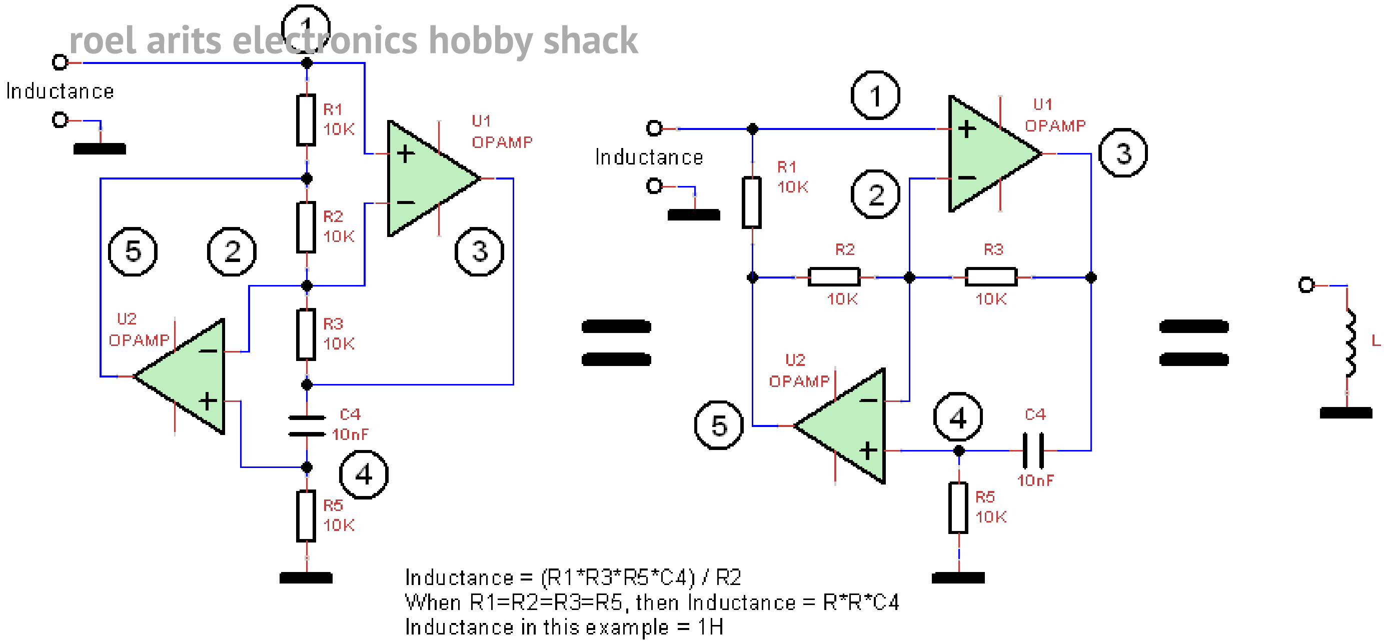
Grounded synthetic (active) inductors

General Impedance converter (GIC)



$$\text{Total impedance } Z = \frac{Z1 * Z3 * Z5}{Z2 * Z4}$$

ıiou grounded synthetic inductor



The Antoniou gyrator is the most versatile type of gyrator and has a very good performance (good Q factor), because it is using 2 amplifiers to compensate for all losses in the circuit. Even with general purpose OPAMPs, good results are achieved.

In the figure above the Antoniou gyrator is used as an active inductor. This kind of inductor is often found in graphic audio equalisers or low frequency filters.

It is not easy to see how the circuit works, because you get the feeling that it's rather black magic than old school physics. In some cases it helps to try to figure out the behaviour of a circuit in the time domain by checking how it responds to a pulse at the input (step-response), instead of trying to understand it's behaviour in the frequency domain by checking how it reacts to varying frequencies.

Often it also helps to redraw the circuit, so the building blocks that form the circuit are revealed. In the right figure, the Antoniou inductor is redrawn in a way that it makes it easier to comprehend.

We will try to figure out the behaviour of the circuit in the time domain and see how it reacts to a step-input. The expectation is that it behaves as a grounded inductor, so when we apply a step to this inductor via a series resistor ([RL-circuit]), we will see a [differentiating] effect. Well, in the right figure, C4 forms a differentiator with R5, which is buffered by OPAMP U2. This part of the circuit is responsible for the differentiating effect. OPAMP U1 plifies the difference between the input (node 1) and (node 2) h gain=1. In fact OPAMP U1 will compensate for the current flowing through R1 by controlling the input of the differentiator via flowing through R1 by controlling the input of the differentiator via it's output (node 3).

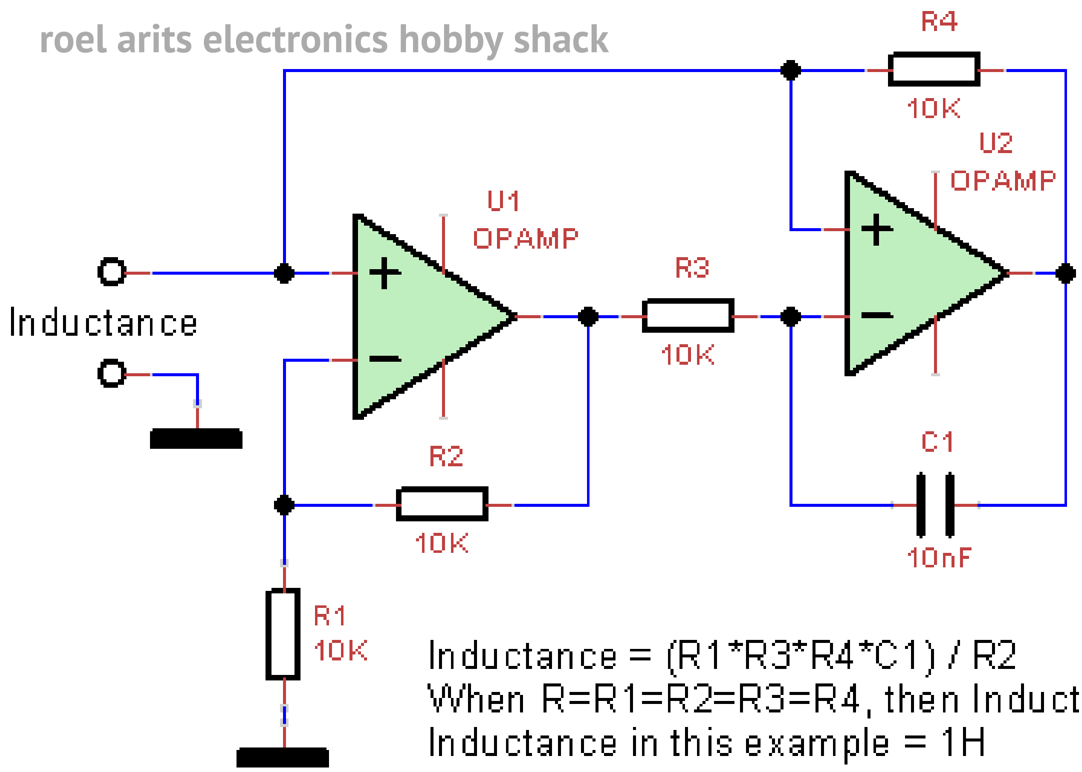
Let's see what happens when we have an input (node1) of 0 volts :

OPAMP U1 will control the output (node 3), so the inverting input (node 2) will become equal to the non-inverting input (node 1). To do this, the OPAMP U1 will put node 3 at 0 volts. Because C4 is discharged, it will have 0 volts over it's terminals, so node 4 is also 0 volts. OPAMP U2 will control the output (node 5), so it's inverting input (node 2), will be equal to it's non-inverting input (node 4), so it will bring node 5 to 0 volts as well.

Let's see what happens when we suddenly increase the input voltage :

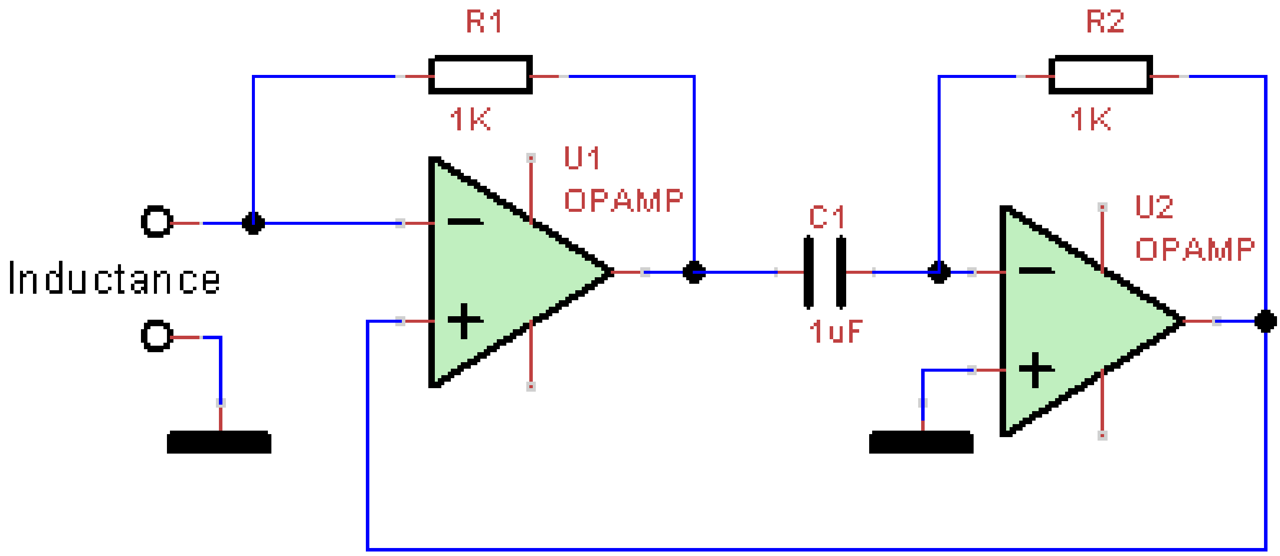
OPAMP U1 will increase the output voltage at node 3 high to make the difference between node 1 and node 2 equal to 0 volts. When node 3 raises, capacitor C4 will start charging via R5, so the voltage at node 4 will first increase (following node 3) and then drop back to 0, as C4 charges. That is what a differentiator knows how to do. OPAMP U2 will control the output (node 5), so the voltage at node 2 is equal to the voltage at node 4. Node 3 is high, while node 4 drops to 0 over time. So the output of OPAMP U2 will need to drop below zero volts to keep node 2 equal to node 4. OPAMP U1 will try to keep the voltage at node 1 equal to node 2, while OPAMP U2 tries to keep the voltage at node 2 equal to the voltage at node 4. So at node 1, we find the same voltage as at node 4.

Riordan grounded synthetic inductor



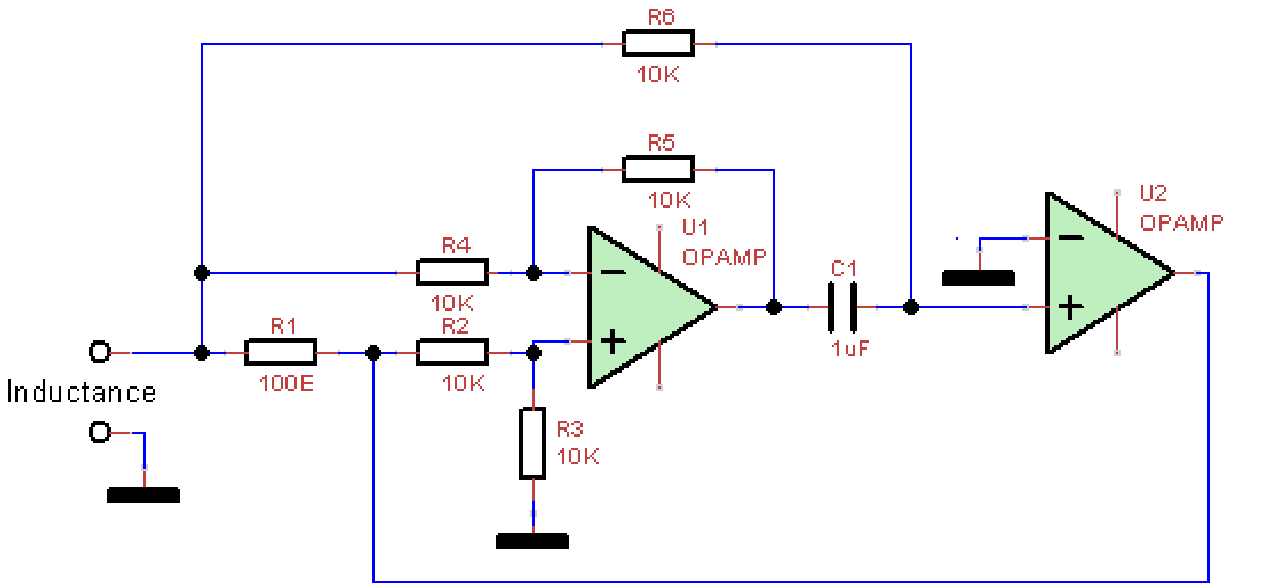
Inductance = (R1*R3*R4*C1) / R2
When R=R1=R2=R3=R4, then Inductance = R^2*C1
Inductance in this example = 1H

Derived from Riordan grounded synthetic inductor



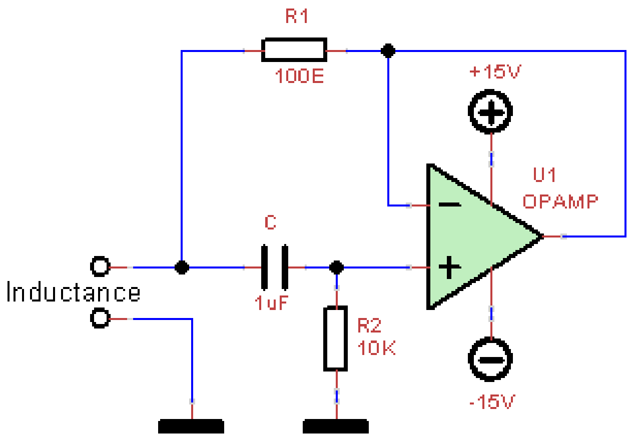
Inductance = R1 * R2 * C1
Inductance in this example = 1H

Current driven synthetic inductor

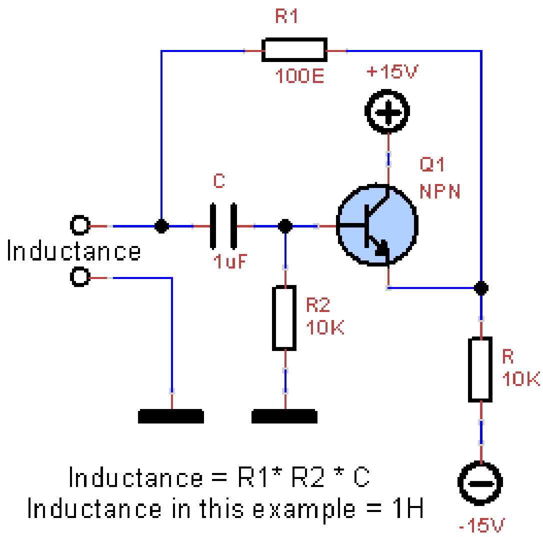


Inductanceis proportional to R1, the gain of the differential amplifier, C1 and R6
Inductance in this example = 1H

Other grounded synthetic inductor circuits with relative good Q factor



Inductance = R1* R2 * C
Inductance in this example = 1H



Inductance = R1* R2 * C
Inductance in this example = 1H

Above circuits can be explained when looking at the behaviour in the frequency domain.

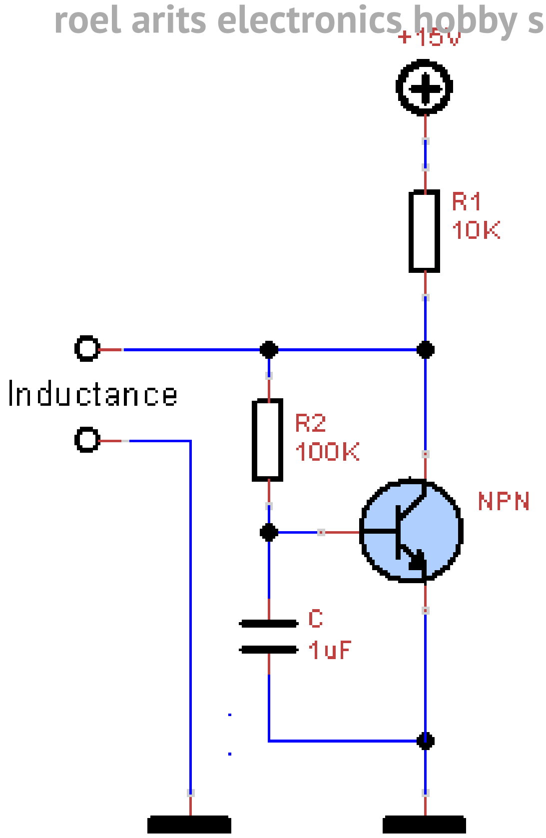
For DC, the capacitor C does not conduct and is an open circuit. This means that the non-inverting input of the OPAMP is at 0 volts. The OPAMP will control it's output in such a way that the voltage at the inverting input is equal to the voltage at the non-inverting input, being 0 volts. With the inverting input at 0 volts, this means that R1 is grounded and connected over the input port. So for DC, the input-port presents a low resistance, being R1. A real grounded inductor is a short circuit for DC, so the circuit behaves like a real inductor with a series-resistor with value R1.

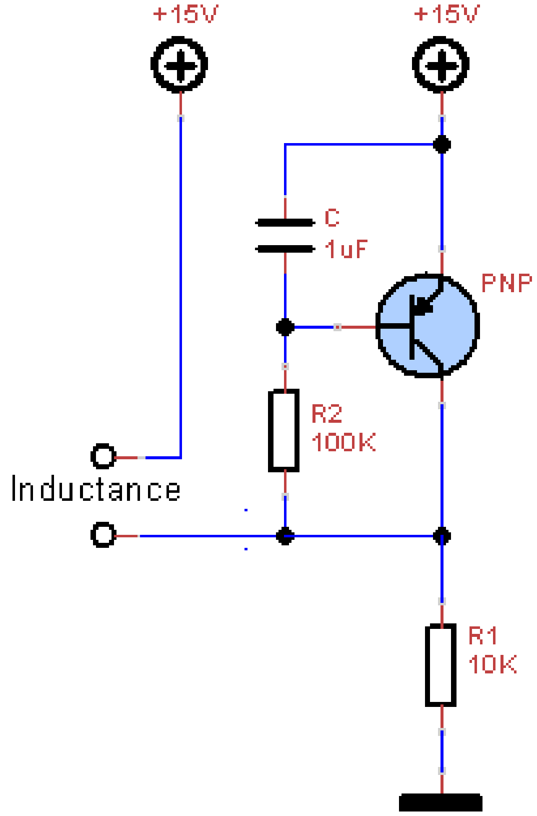
When we increase the input frequency, C will start to conduct and the signal at the non-inverting input of the OPAMP will start to increase. This means that the output of the OPAMP will also start to increase. Seen from the input port, this means that less and less current will flow through R1 and more and more current will flow through R2.

At infinite frequency, C is a short circuit, so the OPAMP just passes the input signal to the output. So the current through R1 will be 0, because the signal at both sides of R1 will be equal, begin the input signal. Seen from the input port, this means that R2 is the only load impedance. So at infinite frequency, the port represents a high resistance, just like a real grounded inductor would do.

So the circuit behaves like a real grounded inductor.

Other grounded synthetic inductor circuits with low Q factor


+15V
R1
10K
Inductance
R2
100K
NPN
C
1uF


+15V
+15V
C
1uF
PNP
R2
100K
Inductance
R1
10K

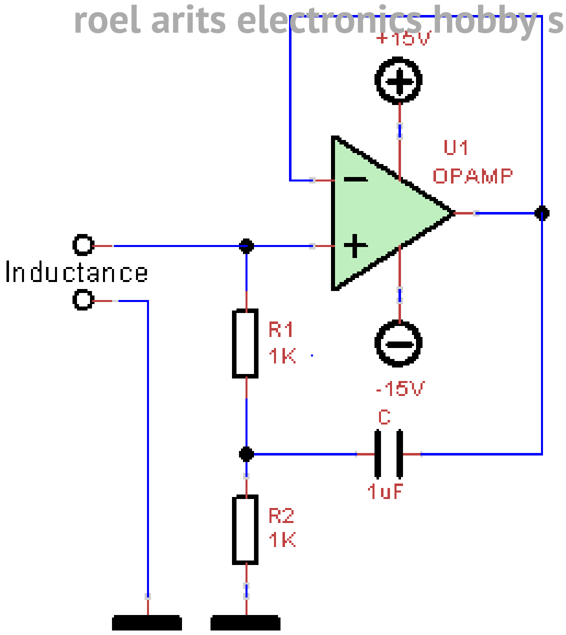
The transistor circuits above (borrowed from an EDN article) simulate an inductor which value depends on the collector current and the Beta (current-amplification factor) of the transistor. Their behaviour can easily be understood when checking in the frequency domain with a signal source connected to it via a resistor, forming a RL circuit :

With a low frequency input, the capacitor will have a high impedance, so most of the current flows into the base of the transistor causing it to conduct. When the transistor conducts, the collector is grounded, so we see a short circuit when we look into the input port. This is the same behaviour as a real inductor.

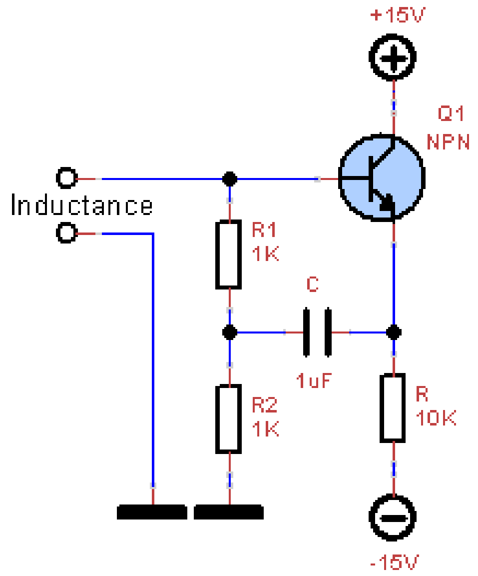
When increasing the frequency of the input signal, the capacitor impedance will decrease and will steal current from the transistor, causing it to conduct less, so the collector signal increases. So when looking into the input port, while increasing the frequency, we see that the impedance increases. This is also the same behaviour as a real inductor.

Another angle of view to understand the behaviour of the circuit is the phase behaviour :

The integrating RC combination causes a phase shift of maximum -90 degrees. The transistor is an inverter and generates a phase shift of 180 degrees. Both together will cause a phase shift of maximum +90 degrees. A real grounded inductor would generate the same phase shift when connecting a signal source via a resistor (RL circuit). So concerning phase shift, the circuit behaves as a real inductor.



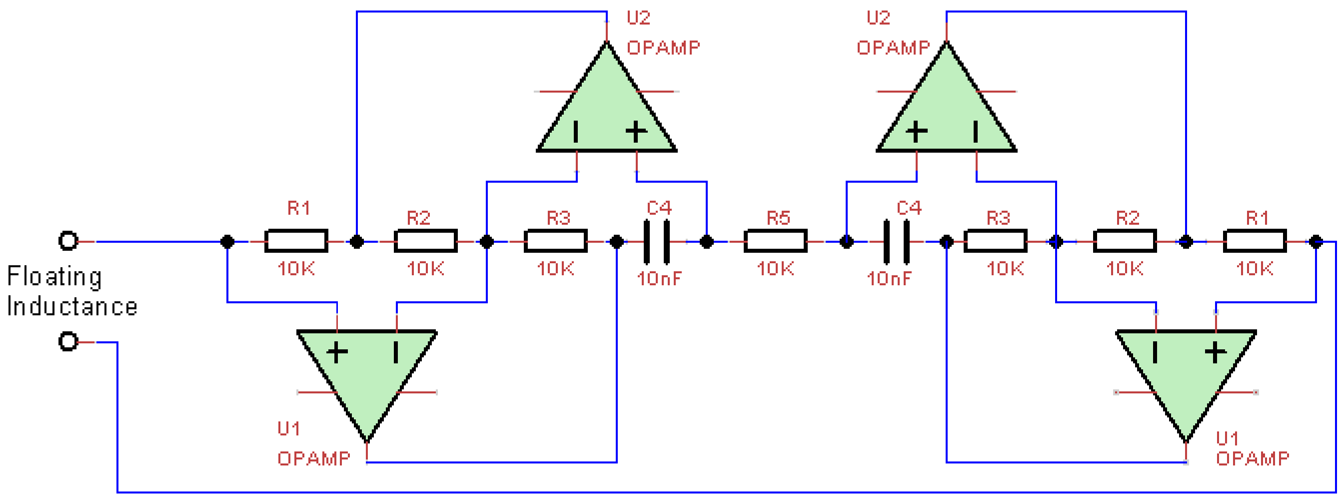
Inductance = R1* R2 * C
Inductance in this example = 1H



Inductance = R1* R2 * C
Inductance in this example = 1H

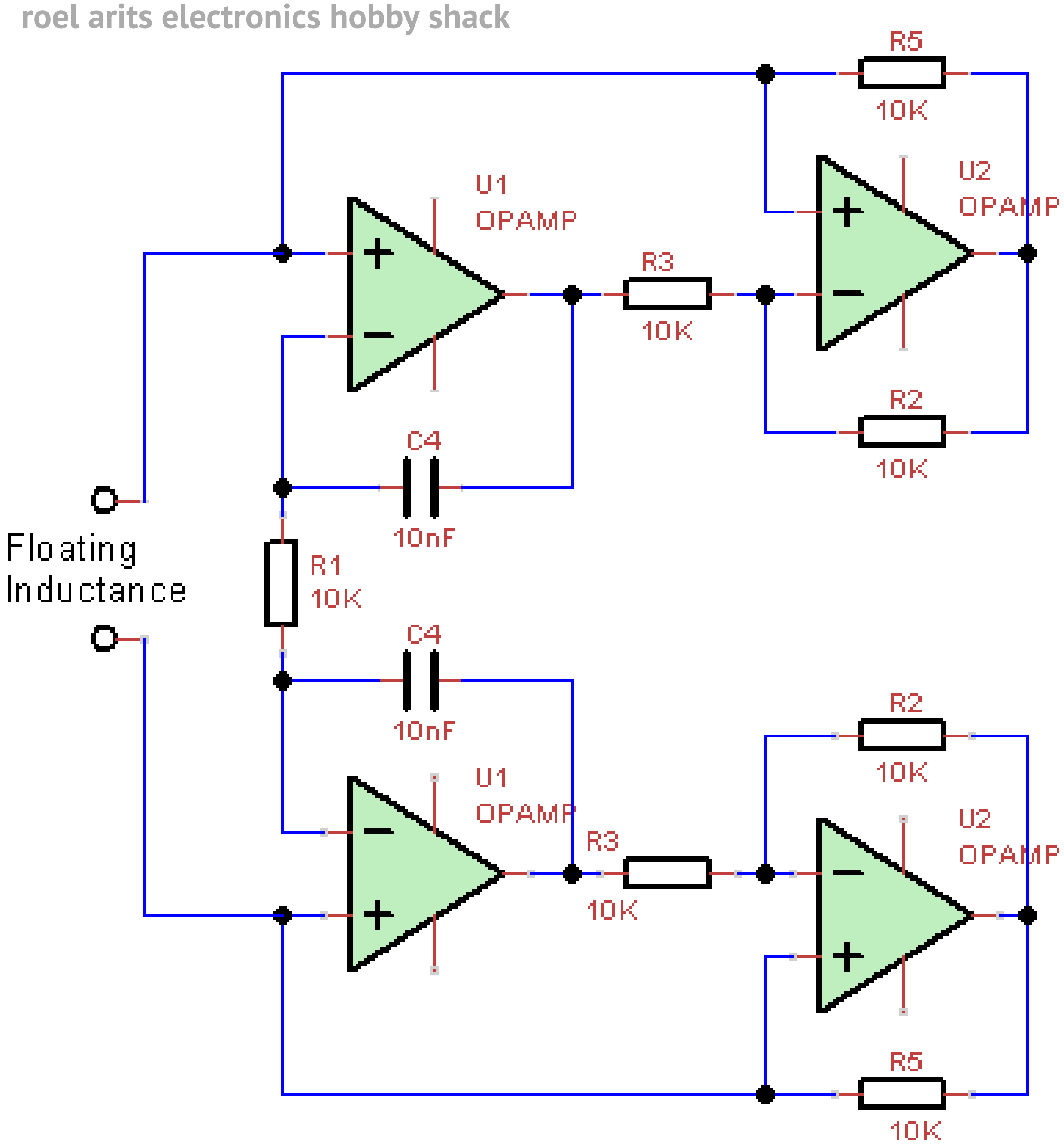
Floating synthetic (active) inductors

Antoniou floating synthetic inductor



Riordan floating synthetic inductor

Bob Pease floating synthetic inductor


R5
10K
U1
OPAMP
U2
OPAMP
R3
10K
R2
10K
C4
10nF
Floating
Inductance
R1
10K
C4
10nF
R2
10K
U1
OPAMP
U2
OPAMP
R3
10K
R5
10K

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