Summary of Robust Mechatronics
MF2043

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1 Power Supply

There are two types of regulators: *switching* and *linear*. In linear regulators, voltage is regulated via feedback controls. Can only handle voltage-dropping applicatins. They are not very efficient but are noise free.
Switching regulators use transistors transfer energy via over inductors or capacitors. This kind of regulator are much more efficient than the linear type but also generate noise.

Linear regulators

There are two types of linear regulator, shunt and series-pass.

Shunt regulator

A shunt regulator uses a zener diode to regulate ouput voltage. It utilizes the fact that a zener diode allows back current when subjectet to a voltage above the *zener voltage*, V_z. In the shunt regulator, $V_z = V_{out}$. This type of regulator has a number of drawbacks, namely

- V_{out} cannot easily be chosen, it depends on available types of zener diodes.
- V_z changes with input voltage, V_+ and zener current, I_z. This is given by the equation
$$I_z = \frac{V_+ - V_z}{R} \tag{1}$$
- Since I_z must be chosen to be large enough, using R, the voltage source is running at full current all the time.
- A high power zener is required to accommodate large load currents.

The diagram for the shunt regulator is displayed in Figure 1

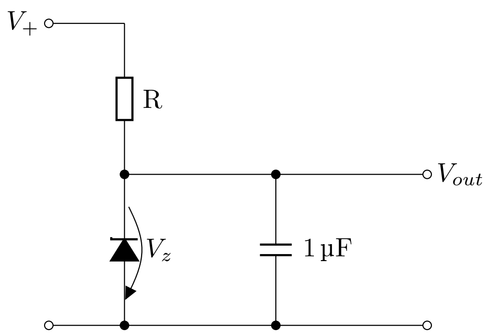

Figure 1: Shunt regulator circuit

The capacitor is used for output filtering and R is used to adjust I_z.

Series-pass regulator

To remove the need for a power zener, one might use a series-pass regulator, depicted in Figure **??**. This uses an *emitter follower transistor* to regulate voltage. The output voltage is then $V_{out} = V_{ref} - V_{BE}$. An emitter follower npn transistor has current gain but no voltage gain. This setup has the problem that that V_{BE} varies with output current. This is alliviated by putting a op amp at the base of the transistor, fed back from a voltage divider at the output. This also allows the circuit to be adjusted.

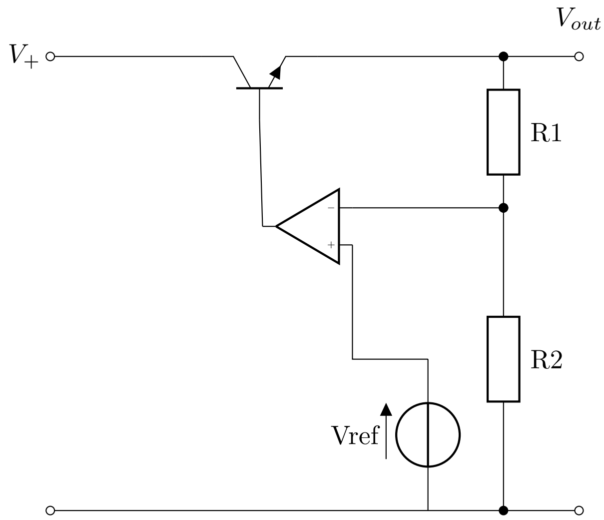

Figure 2: Simple series-pass regulator.
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Switching regulators

There are several types of switched regulators. These can both switch up or down the voltage.

Step-Down (Buck/Forward mode) Converter

A step down converter (Figure **??**uses an inductor and a switch to make the output voltage lower than the input voltage. It can generate high output power, up to kW and produces less ripple than a Boost mode converter.

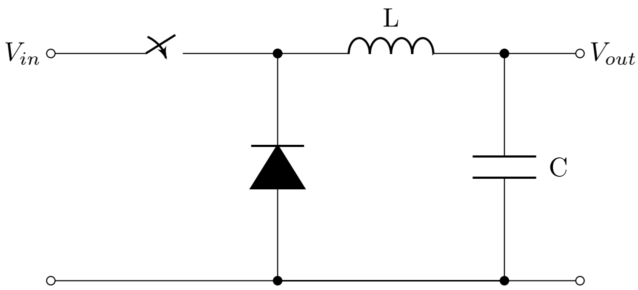

Figure 3: Step down converter.
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It operates in two stages. I the first stage, the switch is closed and the inductor is charged . In the second stage, the switch is open and the inductor is discharged via the load and through the diode. There are some losses over the diode, so a second switch might be used there instead. The circuit is then running in *synchronus mode*. The capacitor C is used for smoothing the output voltage. The output voltage is dependent on the PWM duty cycle, D, and is simply

$$V_{out} = DV_{in}. \tag{2}$$

Assuming ideal components, the input power must equal the output power and therefore

$$I_{in} = I_{out}\frac{V_{out}}{V_{in}} \tag{3}$$

must hold. Also, the output current is equal to the difference between the minimum and the maximum current over the switch, ΔI,

$$I_{out} = \Delta I_{in} \tag{4}$$

The switching is shown in Figure 4

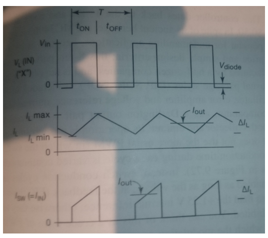

Figure 4: Swithcing of Buck regulator

Step up (Boost mode) converter

A Boost mode converter is a rearranged Buck converter, shown in Figure **??**. The boost mode converter delivers higher output voltage than the input voltage.

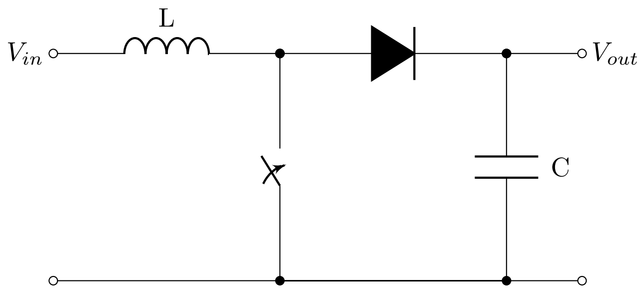

Figure 5: Step up converter.
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It does so by charging the inductor when the switch is closed. When the switch is opened, the voltage before the diode goes up and the inductor dumps it's current into the diode. The regulator can be run in either continuous or discontinuous mode, during which the current drops down to 0 between switching. The current over the inductor (in current) is given by

$$I_L = DV_{in}\frac{T}{L}. \tag{5}$$

Running in discontinuous current mode (DCM) causes bigger ripple than continuous mode (CCM), though CCM regulators can get unstable.

Isolated converters

There are also galvanically isolated converters. These exhibit positive traits, such as built in filtering and good in/output isolation. The isolation can lead to problems with ground since in- and output cannot share the same ground. They are also expensive.

Types of capacitors

There are several types of capacitors. A short list of pros and cons of different types are listed below in Table **??**

Type	Pros	Cons	Application
Metal foil	Low carbon, less fire risk	Big size	-
Polypropylene	Low loss, high stability	Big size, Costly	-
Polyester	Small, low price	Low performance	-
Polyphenylene Sulphite	High temp, low loss, high stability	Low voltage	-
Plastic foil	Low cost, low resistance	Low freq, stability	Decoupling, Filters and timing circuits.
Ceramic	High stability, temp, freq, time, voltage	Cost, Low F	High freq
Electrolyte	High C anv V, Dry: Age	Polar, Dry: Low V	Wet: Power supplies
Tantalum	-	Small F	-

Table 1: Different types of capacitors

The quality of a capacitor has low damping. Given damping factor d, quality is given by

$$Q = \frac{1}{d} \tag{6}$$

where

$$d = \frac{R_s}{X_c}. \tag{7}$$

The impedance of a capacitor is given by

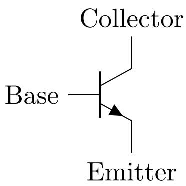
$$X_c = \frac{1}{\omega C} \tag{8}$$

2 Interface for microcontrollers

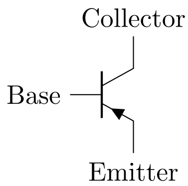
Interfaces are connected to a microcontroller, giving it the ability to affect its surroundings. Examples of interfaces are light, sound, peripherals, sensors, displays, heat elements and actuators. Sensors and actuators are types of *transducers*. A transducer is something that *transforms one type of energy into another.*

Bipolar transistors

Bipolar transistors come in two flavors, described in Figure 6a and 6b.

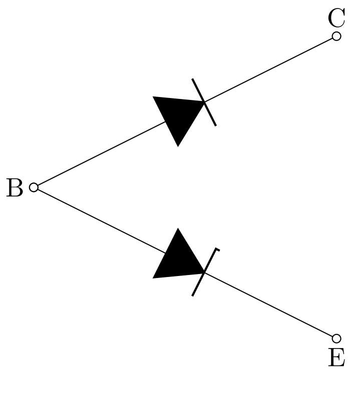


(a) A npn transistor.

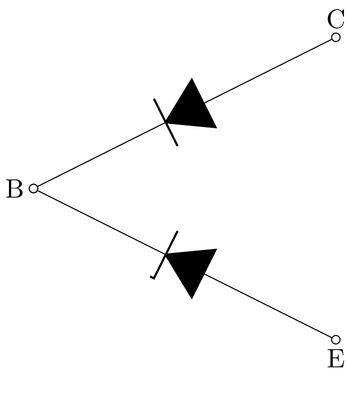


(b) A pnp transistor.

As a memory rule, one can think that the emitter *enteres or exits* the transistor and that a pnp *penetrates* into the transistor. The transistor can be seen as a sort of amplifier, amplifying a small current across the base over the collector and emitter. The differences between the npn and pnp types is in how the current flows through the collector-emitter. In an npn transistor, the current flows *from the collector to the emitter.* For a pnp, the other relation applies. Also, an npn transistor is on when there is a high potential on the base. The opposite is true for a pnp where it switches on when the base is low. For an ohm-meter, the transistor types are viewed as in Figure 7a and 7b.



(a) A view of an npn transistor seen as from an ohm meter.

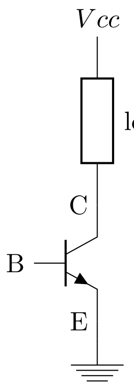


(b) Same for a pnp transistor.

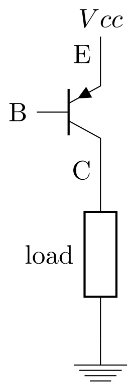
For an npn transistor, *the collector must have a higher potential than the emitter.* The opposite is true for a pnp transistor.

Connecting a load to a transistor

When connecting a load to the transistors, the load is connected differently depending on transistor type. Figure 8a and 8b shows how to connect the load.



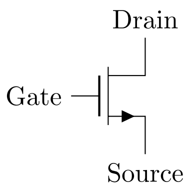
(a) Load on an npn transistor.



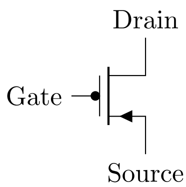
(b) Load on a pnp transistor.

Field Effect Transistors

Field Effect Transistors, or *FETs* are transistors that do similar tasks to bipolar transistors. They also have 3 ports, Gate (Base), Drain (Collector) and Source (Emitter). One important difference is that in a FET, the Gate draws nearly no current. Just like with the bipolar case, there are two types of polarities, *n-type* and *p-type*. These are displayed in Figure 9a and 9b.



(a) An n-type MOSFET.



(b) A p-type MOSFET.

A FET has a behaves rather like a resistor for V_{DS} and can therefore be seen as a variable resistor R_{DS}.

Modes

The FETs can be run in two modes, *enhancement* and *depletion*. In enhcancement mode, Figure **??**, R_{DS} is very high at 0 V potential difference at V_{GS}.

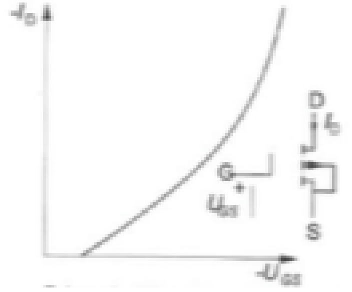


Figure 10: N-type FET run in enhancement mode.
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In depletion mode, Figure **??**, the FET has some resistance when V_{GS} is at 0V. Current will the pass through DS.

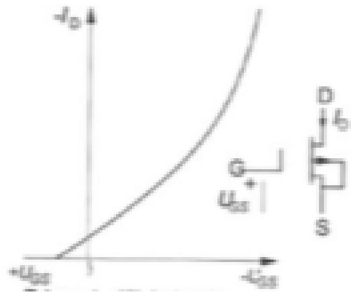

Figure 11: N-type FET run in depletion mode.
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3 Filters

Filtering is used to dampen, or *atteutate*, signals of certain frequencies. They're used in a variety of applications and come in many different types. To describe the different filters characteristics, certain critera are examined. Filtering might be needed to filter out noise from quantization(resolution), mechanical noise and noise from electric disturbanses.

Filter characteristics

Performance of a filter can be viewed from two different domains, the *frequency domain* and the *time domain*. These are interconnected and are both used, though for general description of a filter, most often the frequency domain is used.

Frequency domain characteristics

The frequency domain contains information on how the signal through a filter is attenuated at different frequencies, as well as how the singals phase is shifted, called *phase shift*. Most commonly, the frequency domain is reached by *Laplace transformation* to the variable s, though the *Fourier transform* might also be used. s represents the the complex frequency $j\omega$. The cutoff requency f_c is described as the frequency at which the signal has dropped by 3dB. Before f_c is the *passband* and after comes the *transition region* which stops at the *stop band*, defined by some minimum attenuarion, for example 40 dB. The earlier described *phase shift* is important because when different frequencies of a signal don't have the same phase shift, the waveform might come out distorted.

Time domain characteristics

The time domain describes the behaviour of the output signal when different functions such as step and ramp are run through the filter. These include *rise time*, the time it takes for the signal to go between 10% and 90% of its maximum value. The time before the signal settles indefinitely within a predefined limit, often 5%, is called *settling time*. The delay before the signal reaches 10% of its max is called *timedelat* and the *overshoot* indicates the absolute maximum value the signal reaches relatively to the steady state value.

Discrete vs continuous filters

Describing a filter in continuous time is done using Laplace transformation. Laplace transform is given by the equation

$$L\{u(t)\} = \int_0^\infty u(t)\mathrm{e}^{-st}\mathrm{d}x \tag{9}$$

and this has the important properties that integration equals to

$$\mathscr{L}\left\{\int u(t)\mathrm{d}t\right\} = \frac{1}{s} \tag{10}$$

and derivation to

$$\mathscr{L}\left\{\frac{\mathrm{d}u(t)^n}{\mathrm{d}t}\right\} = s^n. \tag{11}$$

In the discrete case, the *z-transform* is used. This is defined as

$$\mathrm{X}(z) = \mathscr{Z}\{x[n]\} = \sum_{n=-\infty}^{\infty} x[n]z^{-n} \tag{12}$$

with the the important shift property,

$$\mathscr{Z}\{y[k+n]\} = z^{-ny(k)}. \tag{13}$$

The z-transform and Laplace are related by

$$z = \mathrm{e}^{sT_s}. \tag{14}$$

The type of modeling of the filter depends on the implementation. Continuous time filters are generally used when designing analog filters and is a quick way of creating low order filters. Laplace modeling gives a quick understanding of the signal properties in time.
Discrete filter design on the other hand is mainly used when designing digital filters. Since it is done using a computer, higher order filters can easily be created and there are many types of filters easily available such as FIR filters (no denominator), Chebyshev, Butterworth and Bessel filters.

4 Introduction to EMC

This lecture covers disturbances in electircal circuits, such as common mode current, Electro Magnetic Pulses and Electro Static Discharge. Distrurbances are gathered under the name Electro Magnetic Interference, or *EMI*, and the amount of EMI a circuit generates is related to Electro Magnetic Compatibility, *EMC*. A good EMC means low or no interference.
EMP occurs during lightning strikes and nuclear blasts. The power of an EMP blast is very high but only lasts around 50 μs and does as such not contain much energy.

EMC Characteristics

EMC can be transferred to and from a system in two ways, radiation and conduction. A systems EMC characteristics are therefore divided into Radiated Emission (RE) and Radiated Immunity (RI) as well as Conducted Immunity (CI) and Conducted Emission (CE). The frequencies of these emissions and immunities have shifted over the years to a point where both emission and the receptability of disturbances are now in the same area. This is described called the *Compatibility funnel*.

Signal traces

A circuit with contains a changing current becomes an antenna, emitting electro magnetic waves. There are several types of antenna, three of wich are shown below.

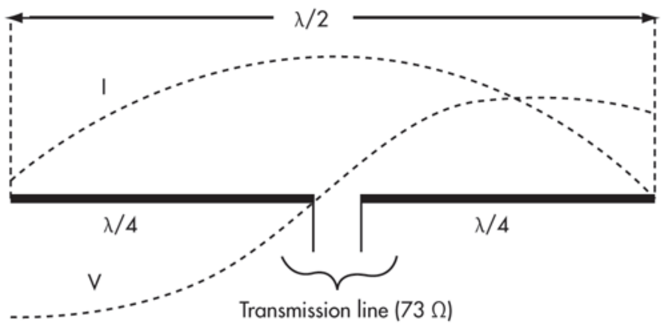

Figure 12: A dipole antenna.
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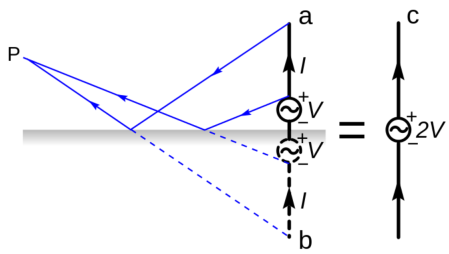

Figure 13: A rod antenna.
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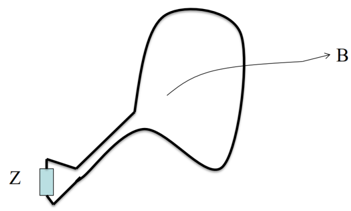

Figure 14: A loop antenna.
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If a the layout of a circuit is not designed properly, it might exhibit antenna like behaviour, leading to EMI. Especially loop antenna phenomenon are common in parts of a closed circuit where current is alternating frequently but there are also examples of dipole antenna behaviour. In general, it is desired to let the return current be able to run directly underneath the feed current line. This is what the current will do unless hindered. Figure **??** displays a two-layer board where the return current is forced to take a longer return route, causing a loop antenna and therefore reducing its EMC.

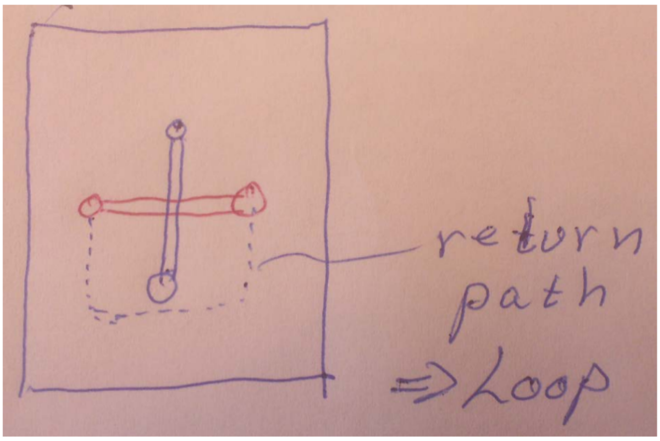

Figure 15: A loop antenna in a two-layer PCB.
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The best solution is to not cut in the ground plane, thus leaving the return paths as untouched as possible. It is also important to avoid sharp edges in the signal trace since this causes reflection and radiation.

Coupling modes

The voltage differences within a circuit are called *Differential mode* voltages. These are normal and cause the current to flow in the closed circuit. When the voltages within the circuit change together is called *Common mode*. This causes the current to flow in the same direction in all cables and is present even when there is no visible connection to the surroundings. Common and differential modes is displayed in Figure **??**.

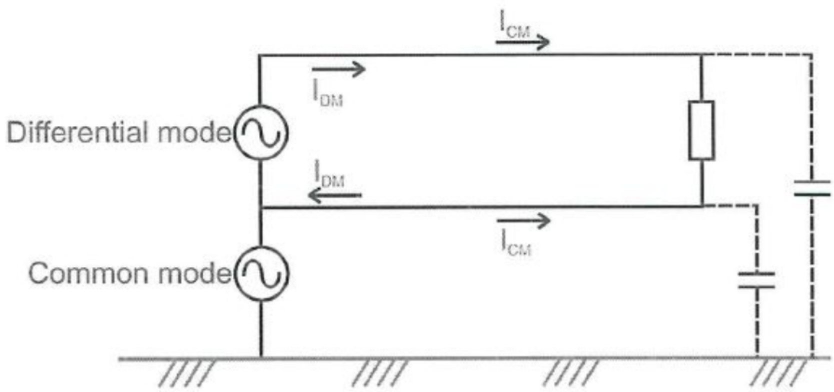

Figure 16: Different coupling modes.
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Because the common mode current is dependant on the common mode impedance, sometimes grounding is not desired since a lower impedance causes a higher current. This is demonstrated in Figure **??**.

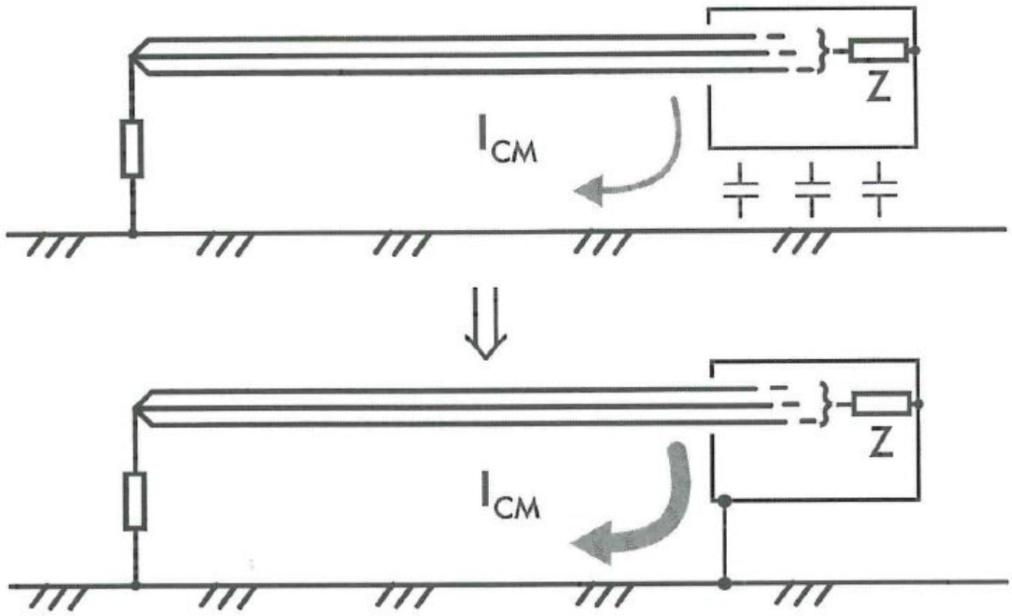

Figure 17: Different coupling modes.
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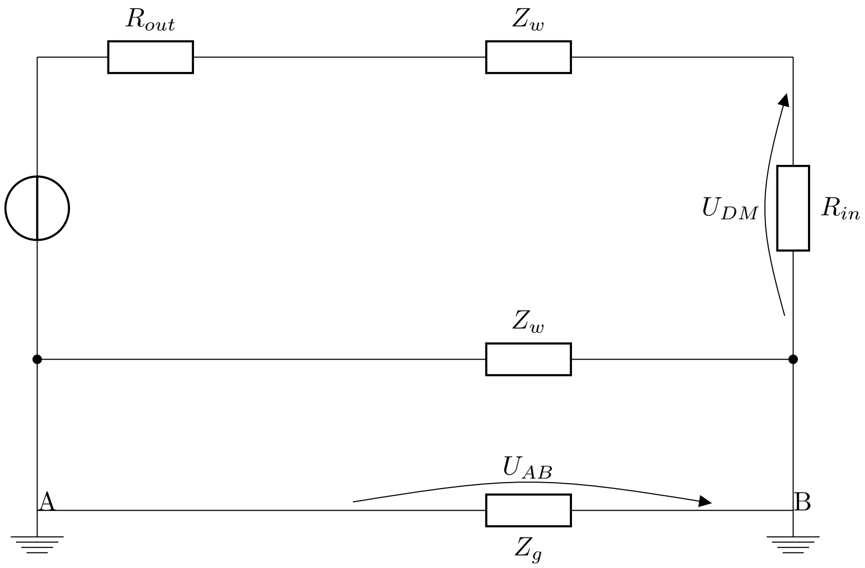
When calculating the interference the common mode current has on the differential mode current, the model in Figure **??** is useful.



For the interference, the following equation is true,

$$U_{DM} = \frac{U_{CM} R_{in}}{R_{out} + R_{in}}. \tag{15}$$

Example 4.1
For a circuit as in with

- $R_{in} = 1\text{M}\Omega$
- $R_{out} = 1\text{k}\Omega$
- $U_{CM} = 0.1\text{V}$

The Differential mode interference is

$$U_{DM} = \frac{U_{CM} R_{in}}{R_{out} + R_{in}} = \frac{0.1 \cdot 1}{1 \times 10^3 \cdot 1 \times 10^6} = 0.1\text{V}$$