Summary MF2043 - Robust Mechatronics

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1 Development models

1.1 V-Model

The V-Model is used when developing new products. It is a way to model both hardware and software and is used broadly in the industry. It has ist name from its v-shape where the horisontal axis represents time and the vertical axis represents level of abstraction.

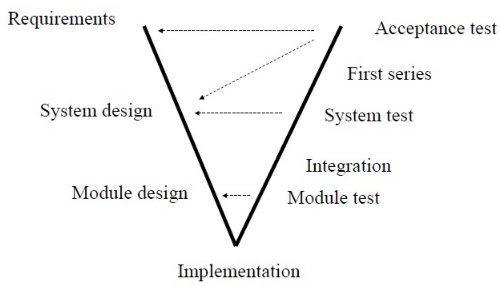

Figure 1: Graphical representation of the V-Model

There are seven different core activities, **Requrements analasys** is the first step and there are collected by analyzing the needs of the user(s). It is important to make the requirements measurable so that it will be fairly easy to see if they have been fulfilled or not. The **system design** is where the engineers analyse the buisness of the proposed system from the requirements. Their job is to figure out the possibilities and techniques by which the requirements can be implemented. This is more high level than the next step, **module design** this is the lower level design where the system is broken into smaller units or modules. Each one of them is explained in detail so the programmer can start coding directly. At the bottom of the V we have the

implementation part where all the parts are implemented and put together into one system. After the implementation step the testing starts. First is the **module tesing** where the individual module is tested. These are often UTPs (Unit Test Plans) and these are executed to eliminate bugs at code level. Next is the **integration testing** where the coexistance and communicaton of the modules is tested. The **system testing** is done to ensure that the expectations of the customer is met. Once the system testing is complete, ther will be a **first series** done. After all this the final test is the **user acceptance testing** or UAT. These tests is done in the user enviroment it is supposed to opperate in.

1.2 General mechatronic development

It is important to have the whole system in mind and to look at all diciplines when developing the system. It is important to have the software developers develop testing frameworks for the hardware early in the process and the mechanical designers to have the cabling in mind when designing the mechanical system. It is also important to see the specifications as dynamic, they will change during the work process.

2 Operational Amplifier

The two **golden rules** for op amps:

1. The output attempts to do whatever is nessesary to make the voltage differance between the input pins zero. (It "looks" at its input terminals and swing its output terminal around so that the external feedback-network brings the input differential to zero.
2. The inputs draw no current.

2.1 Inverting

Let's look at the inverting amp in figure 2. With the golden rules in mind we can see that:

1. The + pin is to ground (might also be to ref) so rule 1 implies that - also is.
2. This must mean that the voltage over R_f is V_{out} and that the voltage over R_{in} is V_{in}.

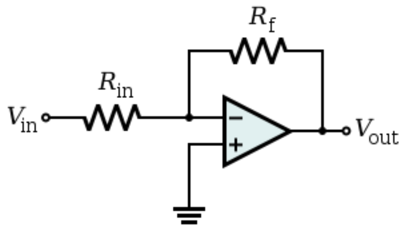

Figure 2: The inverting OP-Amp

3. Using rule 2 we have

$$V_{out} = -\frac{V_{in}R_f}{R_{in}} \tag{1}$$

So, how does this work? Let's for simplicity say that $R_f = 100k\Omega$ and $R_{in} = 10k\Omega$ and the input is $+1V$. Let's say for the sake of the matter that the output is uncooperative and sits at zero. What happens? R_f and R_{in} form a voltage divider, holding the invertign input at $+0.91V$ The op amp sees the enormous inbalance and forces the output to go negative. This will continue until the output is at it's requred $-10V$. At this point is both the inputs at the same voltage, ground. This also means that any tendency to lower the volt lower than $-10V$ will pull the inverting input below ground forcing the output to rise. The downside with an inverting amplifier is the low input impedance
The - pin can be connected to a reference voltage meaning that it will use this as a virtual ground and in so "lifting" the output to an offset. This can be used when using a inverting configuration for an implementation where the sign invertion is undesired.

2.2 Non-Inverting

The non-inverting operational amplifier as seen in figure 3 have the desired infinite input impedance. This is almost true for most amps, some, like a JFET 411 input it would be 10^12. The output impedance is however still a fration of an ohm.
The simple analisys will give that $V_- = V_{in}$ but V_- comes from a voltage divider, $V_- = V_{out}/(R_g + R_g)$. Set $V_- = V_{in}$ and you will get a gain of

$$G_V = 1 + \frac{R_f}{R_g} \tag{2}$$

As seen from equation 2 the maximum gain of an non-inverting amplifier is 1. This makes the non-inverting amplifier unsuitable for some applications.

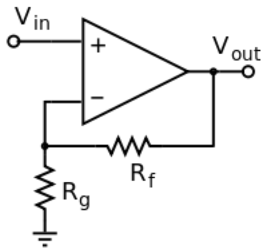

Figure 3: Non-Inverting Op-Amp

3 Filters

A filter is a circut or a software that performes signal processing functions to remove frequency components from the signal, to enhance wanted ones, or both. There are many types of filters some will be covered below.

3.1 Analog

The analoge filter is a filter that will process the analog signal, comming straight from the harware. The source will often be a sensor of some sort, vibration, sound, temperature, extension etc.

3.1.1 Anti-alias lowpass filter

Aliasing is an effect where different signals will become indestinguishable when sampled. If a signal with noise is sampled there will be no way of differentiatiating the noise from the signal. There is a variety of implementations for when a analog signal will be digitilized, audio beeing one of the most intuitive. The convertion between analog and digital is done by sampling the amplitude of the analog signal and convert each sample to a numeric quantity. This process can introduce artefacts, or missleading amplitudes due to both the finite accuracy by which the values are quantizied and brought from the continuos to the descrete and from the finite rate at which these samples are taken. The **Nyqvist criterion** says that the signal beeing digitilized can not contain frequencies that exceeds half the sampling rate f_s. This is usualy accomplished by passing the signal through a **anti-aliasing filter** whose cutoff frequency f_c ensures thorough attenuation of signals above the Nyqvist frequency $f_s/2$. In short the banwidth of the signal is restricted to satisfy the samplin theorem that states that the unambiguous reconstruction of the signal from its samples is possible if the power of the frequencies over the Nyqvist criterion is zero. In real life it is a trade off between bandwidth and aliasing.

(1) Example:
You have a signal from a sensor that you are sampling at $f_s = 1kHz$. What should be you cutoff frecuency f_c?
Answer: $f_c = f_s/2 = 500Hz$ Due to the Nyqvist criterion.

3.1.2 Passive filters

There are a veriety of different passive filters both high- and low pass. The simpelest filters are presented below.

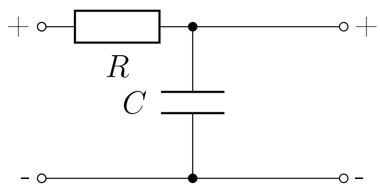

Figure 4: Passive RC low pass filter

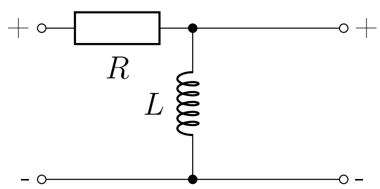

Figure 5: Passive RL high pass filter

The filters seen in figure 4 and figure 5 have counterparts for when using an RC highpass and a RL lowpass. The components will then change place and for the resistor will then connect to ground. The way the RC low pass filter works is that at low frequencies will the hight reactance offered by the capacitor allow almost all of the input signal to develop as an output over the capacitors inductance, X_C. When the frequenzy increases will R become significantly larger than X_C. This will make the circuit attenuate the the higher frequiencies and send them straight to ground. The band of frequencies that the filter will attenuate depends on the value for the components. The components relative value of X_C and R will determine how the gain, V_{out}/V_{in} is different. The gain for a passive filter is always < 1

due to the out impedance beeing too high. The output voltage can be found by using

$$V_{out} = \frac{1}{(1 + \omega^2 R^2 C^2)^{1/2}} V_{in}. \tag{3}$$

The cutoff frequency for a passive filter is found as

$$f_c = \frac{1}{2\pi RC}. \tag{4}$$

The signal driving the filter sees a load of R plus the load resistance at low frequencies, dropping to just R at high frequencies. The worst case source and load impedance of an RC filter are both equal to R.

3.1.3 Active Filters

Active filters ar mainly to gain the amplitude of the the signal. Since a passive filter will result in a voltage drop the active filter might be used where the signal needs to be amplified. This can be useful if the signal sourse e.g. a sensor, feeds very little signal. It us also useful due to the fact that is can feed more current than the source can. The active filter is most often built of an operational amplifier.

A **first order active low pass filter** will be a inverting amplifier and a capacitor in parallel with R_2 as seen in figure 6 This will have the amplifica-

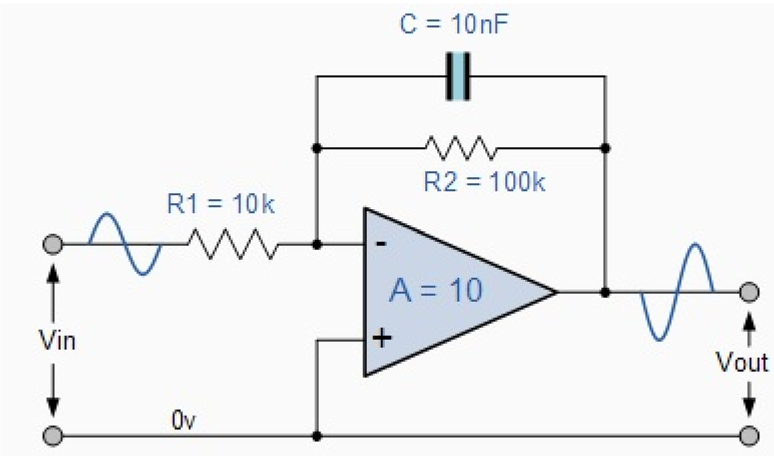

Figure 6: Inverting first order active low pass filter

tion,

$$A_N inv = -\frac{R_2}{j\omega C R_1 R_2 + R_1} \tag{5}$$

and the cutoff frequency,

$$f_c = \frac{1}{2\pi R_2 C}. \tag{6}$$

The non-inverting amplifier have the advantage of having a very high impedane

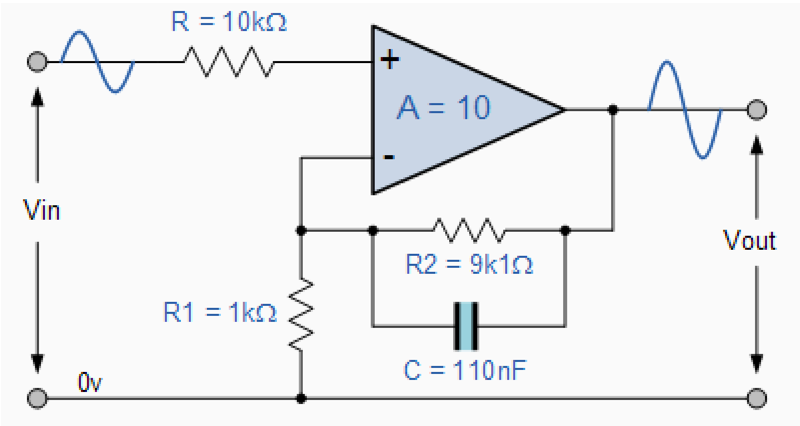

Figure 7: Non-Inverting first order low pass filter

between the input pins. But the sam problem as previously disscussed apply here, the lowest amplification is 1, meaning that the amplifier can not be used to damp a signal. There solution will also filter quite badly with low amplifications.
A thing to keep in mind when designing active filters is that resistors and capacitors must be provided after the set filter charataristics.

3.1.4 Higher order active low pass filter

The Sallen-Key low pass filter is the basis for many of the well known filters such as **Butterworth**, **Bessel** and **Chebyshev** filters.
Butterworth this will give aflat frequency responce in the pass band. To design a butterwort filter, all sections have the same values of R and C given simply $RC = 1/2\pi f_c$
Bessel filters have linear phase or constant group delay in the pass band. They are not that more complicated than the Butterworth. Within each section we have $R_1 = R_2 = R$ and $C_1 = C_2 = C$ but the RC products for each section is different and must be scales. According to this we therefor have $RC = 1/2\pi c_n f_c$
Chebyshev have a steep roll off and a ripple in the passband or the stopband. They have the same calculations as a Bessel filter.

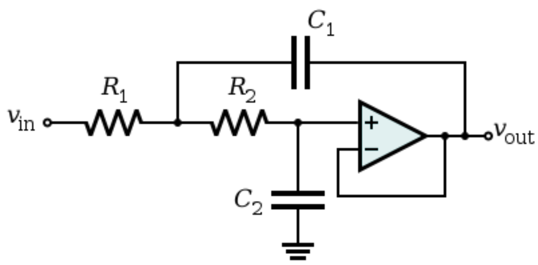

Figure 8: Second order Sallen-Key low pass filter

The filters above are in their standar configuration a secon order filter. To obtain a higher order filter ju simply multiply the Sallen-Key filters, this will give you a even order filter. To obtain a odd order filter ypu simply add one extra single order filter.

4 Power Supply

Due to the vast number of different power sources, ranging from the socket in the wall to solar panels and fuel cells. There is a obvious need for converters and regulators. The regulators can convert AC to DC, DC to DC (regulating) or invert from DC to AC.

4.1 Linear Regulator

The linear regulator is generaly a linear control element in series with the dc input. This is then regulated with a feedback to hace a constant output.
The linear regulator is still widely used for its low noise output in applications where there is a need for precise output. The dissadvantages with the linear regulator is it's low effectiveness due to power dissipation in the control element. This will introduce the need for heatsink and result in wasted power. The output is always lower than the input.

4.2 Switching Regulator

In the switched regulator, a transistor is operated by a saturared switch (oscillator) that periodicly applies the full unregelated voltage across an inductor for short intervals. The inductors current builds up during each pulse storing $E_L = 1/2LI^2$ in it's magnetic field. When the switch is turned off, some or all of the stored energy is transferred to a filter capacitor at the output which also smooths the output. Like the linear regulator, a feedback compares the output with a voltage reference, but it's the ocsillator that controls the output by changing the oscilator frequency. The switcher is nowadays widely used in all types of electronic applications. Since the control element is either off or saturated, there is very little power dissipation. This efficiency is good since less losses means that the components can be made smaller due to the fact that less heat is generated. The downsides is that there output is considerably more noisy than the linear regulator due to the switching.

4.2.1 Step down (buck) converter

The switch is usualy a MOSFET and the diode is used as a rectifier. $V_{out} < V_{in}$ When the switch is closed, $V_{in} - V_{out}$ is applied across the inductor caus-

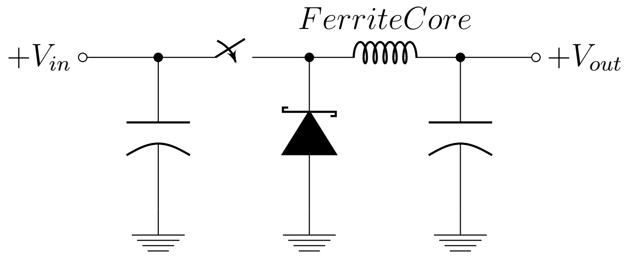

Figure 9: Buck (step-down) converter

ing a linear increasing current $dI/dt = V/L$ to flow through the inductor. When the swich opens, iductor current continues to flow i the same direction with the "catch diode" now conducting to complete the circuit. The inductor now have a fixed voltage $V_{in} - V_{diode}$ across it, causing the current to decrese linearly. The output capacitor acts as a smoother of the inevitable sawtooth ripple. The larger the output capacitor is, the smaller the ripple voltage. To complete the circuit in figure 9, a feedback loop should be added controlling either the pulse, or the repetition rate that compares the output to a reference. The duty cycle can be found as,

$$D = \frac{V_{out}}{V_{in}} \tag{7}$$

It will have lower V_{pp} ripple than the boost mode ande can have a higher power output, up to kW.

4.2.2 Step up (boost) converter

The switch is usualy a MOSFET and the diode is used as a rectifier. $V_{out} > V_{in}$

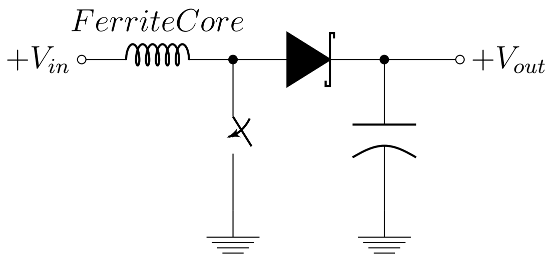

Figure 10: Boost (step-up) converter

The switching regulator can, unlike the linear, produce output voltages higher than the input voltage. When the switch is conducting, the inductor ramps up. When the switch is turned off, the inductor tries to maintain constant current, and the voltage rises rapidly. The diod turns on and dumps current into the capacitor. The output voltage can therefore be much larger than the input voltage. The duty cycle for the boost converter can be found as,

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{8}$$

The boost mode converter can be used when $P_{out} < 150W$. The boost mode can be driven in continuous and discontinuous mode, with a bigger ripple for the discontinuous one and this is also the most common. Continuous can get unstable.

4.2.3 Isolated DC-DC converters

Transformers and optocouplers provide galvanic isolation but this might also be done with a physical barrier on the PCB. This will minimize creeping and will work up until the voltage can creep through the air with a spark or find a conductive way on the PDB.

4.2.4 Buck-Boost

The Buck Boost converter will allow overlap of input and output voltage range. This might be particulary usefull in a battery powered unit. Say you have two AA batteries starting their life at 3V and ending it at 1.8V, here is an obvious implementation for the buck-boost regulator.

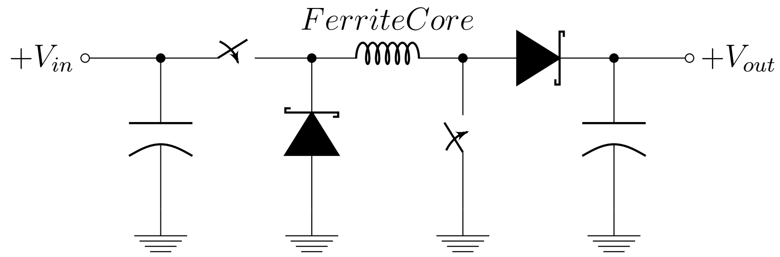

Figure 11: Non-inverting Boost-Buck converter

4.3 Voltage reference

There might be situations where a reference voltage is needed. There are a number of applications where a precision reference is needed, e.g. A/D or D/A conversion, waveform generators or meters etc. There are two styles of voltage references, **2-terminal** (shunt) and **3-terminal** (series). The two-terminal acts lika a zener diode, maintaining a constant voltage drop when current is flowing, thus the external cuircuit must maintain a stable operating current. The three-terminal reference (V_{in}, V_{out} and GND) act like a linear regulator with internal cuircuitry taking care of biasing the internal reference (zenor or something else).

4.3.1 Zener diode

The zener diode is working much like a regular diode operated in the reverse-bias region. And will generally allow significant current if it is reverse biased above its breakdown voltage. The reverse bias is when the p-n junction is operated in reverse, meaning the voltage will basicaly draw the holes in the p-junction (in the p-n junction) further away from the junction and in so increasing the width of the depletion zone and increasing the voltage barrier. There is some downsides to the zener diode, it is very sensitive to temperature fluctuation and the voltage tolarance is poor exept with expencive high precition zeners.

4.4 Thermal characteristics

The regulator is very much in need for temperature awareness. $P_{in} - P_{out}$ gives the power consumed by the regulator but this does not make it obvious for how to claculate the temperature inside the circuit. The temperature also controls the maximum current out, the more power the regulator consumes, the less current will come out from the regulator.

Heatsinks is widely used to get rid of the increased temperatures in the ciurcuts and components. The heatsink might be complemented by a fan or some smart construction making the box work with the cimney effect. The temperature of a die can be calculated with,

$$T_{j(max)} = P_D(R_{\Theta JC} + R_{\Theta CS} + R_{\Theta SA}) + T_A, \tag{9}$$

where j is the die, JC is the junction to case, CS is the case to heatsink, SA is the heatsink to ambient and T_A is the ambient temperature.

4.5 Supply protection

The powersupply needs to be protected against high voltages, reversed voltage, transients etc. Some regulators have buit in protection, and others needs the protection externaly. The protection against reversed polarity is not always there, there is a famous example of the High-Tech Aurora 9 RC airplane radio controller hwo got burnt time after time again. One of the simplest way of having a reversed polarity protection is to have a diode or a couple of diodes like in figure 12 Even though the diode is a great tool, one should

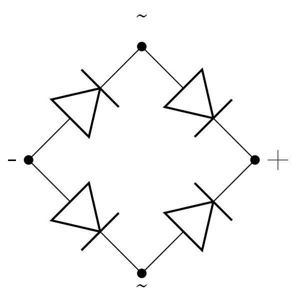

Figure 12: Reverse polarity protection with diodes

not forget that the diode will have a 0.7-1V drop over it.

5 Capacitors

There is a vast variety of capasitors to choose from, here is some of them with their typical application. They are typicaly used for protection against transients and can reduce noise.

1. Plastic foil capacitor generally have low cost and resistance but will only work in lower frequencies and will(exept polypropylene) have stability

problems. They are typicaly used for decoupling, filters and timing circuits.

2. Ceramics are often very stable, they work well in high temperatures and over all freequencies but are more expensive. They are used in applications like oscillators and where demands for high frequency is needed.

3. Electrolytic capacitor have both wet and dry type. Wet are used for high C and V but have a high ESR (Equivalent series resistance) and the electrolyte eveporate, causing them to age. The wet type are typicaly used in power supplies. The dry type age well, have lower ESR and are smaller in size. Since they are used with high voltage they can cause fire, and send backwards voltage, less with higher teperatures.

4. Tantalum electrolyte (μF or pF)