Department of Precision and Microsystems Engineering

Multiplexing piezo electric transducers to reduce the number of amplifiers in an AVC-system

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Multiplexing piezo electric transducers to reduce the number of amplifiers in an AVC-system

For the degree of Master of Science in Mechanical Engineering

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Tijmen Godfroid
June 2022

Abstract

The high-tech industry is constantly searching for methods to make more efficient, more accurate, and faster machines. One of the methods to improve the performance of these machines is active vibration control(AVC) which can help to achieve faster transient responses. One of the ways to achieve this is better controllability which means more actuators to control more modes. These actuators are mostly Piezo transducers in AVC and each group of actuators needs a high voltage amplifier. At some point, the number of amplifiers will be limited by factors such as volume or mass, so if the group of actuators can share an amplifier, that would be beneficial. This can be achieved with time-division multiplexing(TDM). This method in combination with AVC is researched in this thesis. The most important aspects are performance comparison to conventional systems without multiplexing. First, some simulations are done, to show that the TDM is a feasible solution, secondly, a setup is built to check performance and validate the simulations.

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1 Introduction

The high-tech industry is constantly improving its machines to be faster and more accurate. These two goals are highly dependent on each other because when time allows for these operations the accuracy can highly improve. These machines use lots of energy, even when they not fabricating chips, for example for temperature management and vacuum chambers. So more time to fabricate a product means higher costs, which can rapidly increase with for example semiconductor manufacturing equipment. Making machines faster is not the real challenge here, keeping the accuracy when increasing the speed is the real challenge. With higher speeds, we need higher accelerations, and with higher accelerations comes higher forces. These machines are structures that behave like mass spring damper systems, so they react to forces.

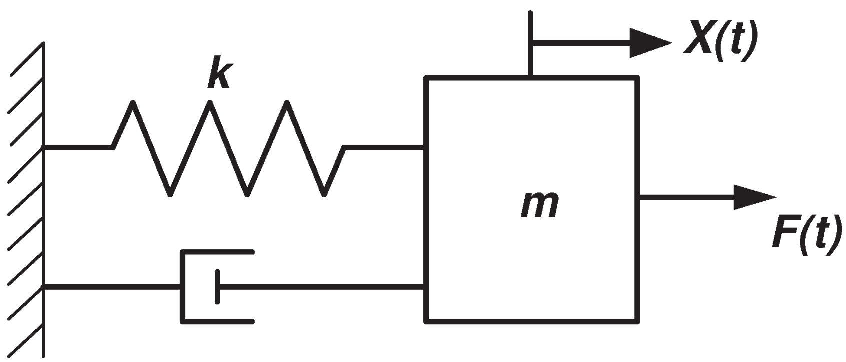

Figure 1: Mass springs damper system [1]

They will vibrate when they are exposed to these forces and depending on the mass, spring constants, or damp coefficients, the structure will vibrate at different frequencies. If the structure can have a higher spring constant, so made stiffer, the structure will only vibrate on higher forces, but higher stiffness normally means higher masses. Higher masses are mostly not wanted. These higher masses mean more power needed from the actuators which have their limits. Also if we look at the formula for the eigenfrequency that is related to mass springs systems there could be seen that higher mass lowers the eigenfrequency, which means more modes get excited which mean more problems.

$$\omega = \sqrt{k/m}$$

So the mass and stiffness are not always the right parameters to achieve higher accuracy and higher speeds. That means the damping needs to be changed to achieve the goal of faster machines because the eigenfrequency is not dependent on this parameter.

1.1 Damping

From the previous section it is shown that damping has an important role to achieve the goal of faster machines. First there will be shown in time-domain what damping does to vibration.

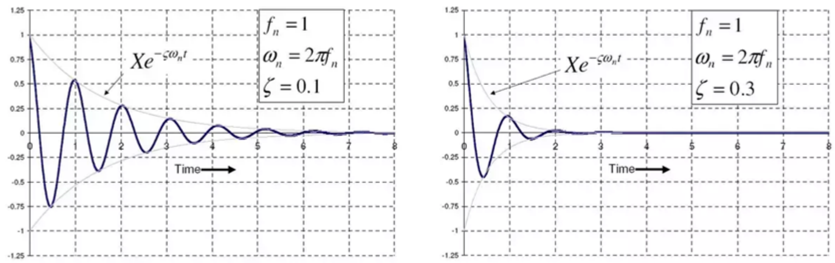

Figure 2: Higher damping coefficient on the right graph [2]

The time it takes for the wave to dampen out between a certain percentage of the original amplitude is called the settling time. There can be distinguished between two types of damping, passive damping and active damping.

1.1.1 Passive damping

Passive damping is damping that doesn't require energy. The pros of passive damping are robustness, costs, and mostly easy application. That means it is widely used in lots of places, for example, as the shock absorber in an automotive vehicle. But imagine this vehicle is used on really bumpy roads and really fast corners as well, for the first one we need a fast response, so lower damping but for the second one we need higher damping since the damping is dependent on time and will run out. This results in the cons of the passive damping, it can only damp a certain frequency. Another con is that the passive damping is mostly heavier, and we want our structures to be as light as possible to be fast and accurate. Therefore active damping is another way to damp without most of these cons.

1.1.2 Active damping

Active damping requires a kind of energy. This energy is mostly controlled by a feedforward or feedback controller. So there is a need to measure the vibration, fed it to a controller, let the controller compute the output, fed that output to an amplifier, and then send it to the actuator. This directly is one of the cons of an active system, there are lots of parts needed which all can fail, which is detrimental to the robustness. The pros of active damping are that it can damp different frequencies with different magnitudes.

1.2 Application

The department of Precision and Microsystems Engineering (PME) on the TU in Delft is doing research on distributed mechatronics under the project name 'MetaMech'. These distributed mechatronics are compliant systems that contain multiple transducers that can act as actuators or sensors. A compliant system is a system without friction because there are compliant joints. Such a structure can be seen in figure 3 and is also called a metamaterial. These metamaterials are designed to use as active materials, which are better in damping structures than passive systems are. Why this is, is explained in literature such as a paper from Madhan [3] and is further out of the scope of this project.

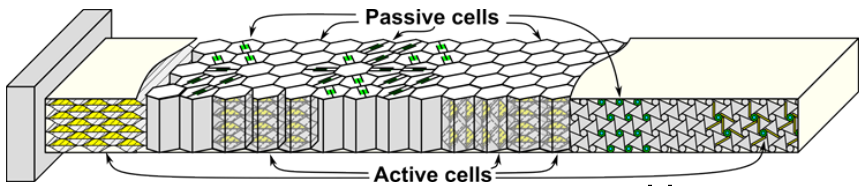

Figure 3: Metamaterial structure [4]

The active material senses the vibrations with for example a piezoelectric transducer, and this signal will be sent to a controller and provide for example an inverted signal of the sensed signal. This signal is sent to the integrated transducers which act as actuators and in this way the material will be damped.

An application where this metamaterial can be used is for example a vacuum wafer gripper from a wafer handler as shown in figure 4.

Figure 4: Vacuum Wafer gripper [5]

A wafer is a silicon plate, used by for example ASML to produce chips, which is very vulnerable. The machines that work with these wafers are high-tech machines with very fast-moving components. If the gripper wants to grab the plate, the gripper can't have any vibration since that will damage the wafer. So this limits the accelerations which is a problem but can be improved with metamaterials. The material of the wafer can be integrated with transducers to create an active structure and this makes it a metamaterial.

1.3 Problem statement

For these metamaterials normally piezo electric transducers are implemented in or on a passive material and they can be used as sensors and actuators. In figure 5 a bending piezo actuator is shown.

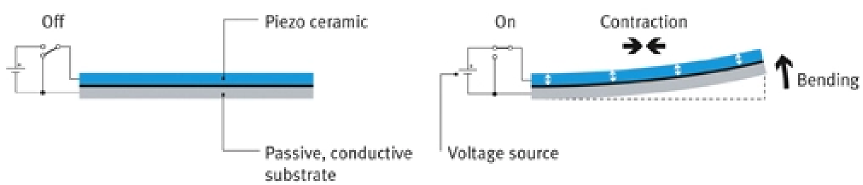

Figure 5: Bending piezo electric transducer [4]

The metamaterial is actually a complete control system like in figure 6.

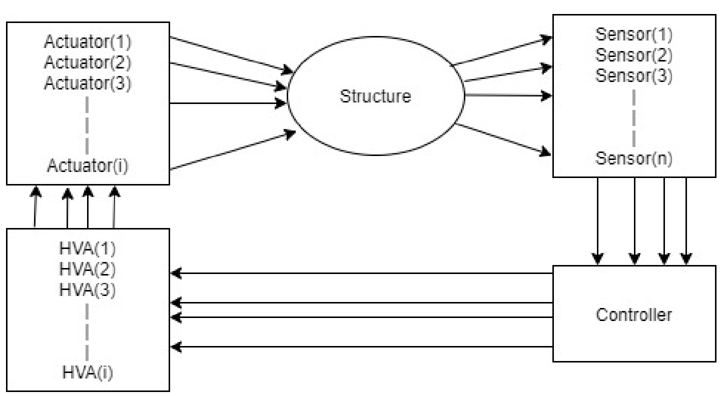

Figure 6: Schematic of control system

The higher number of transducers the better control of the structure will be because of better controllability and observability. In this research the focus will be on the transducers which will be used as actuators which are driven by high voltages. These high voltages are generated by high voltage amplifiers(HVA) and for each actuator a separate amplifier is required. Because of power consumption, money budgets, weight limitations or volume limitations this can become an overall limitation on the amount of actuators which can be used. The industry has a need to do research on a method to use one amplifier for multiple transducers as shown in figure 7.

So this will be the problem statement:

What is needed to design active vibration control with the reduced number of high voltage amplifiers and what kind of performance could be achieved? To come up with a solution for this problem the term 'multiplexing' will be researched, which could be a feasible solution.

1.4 Multiplexing

Multiplexing is a term that is normally used in telecommunication for example computers. A multiplexer is a fast switching device that made it possible to send different groups of data over one communication line. More one this in the literature survey at section 2.2. This multiplexing could work for capacitive power electronics, which is beneficial for the concept of multiplexing piezoelectric actuators since they have capacitive behavior and can mostly be modeled as low-pass filters. More on this in section 2.2

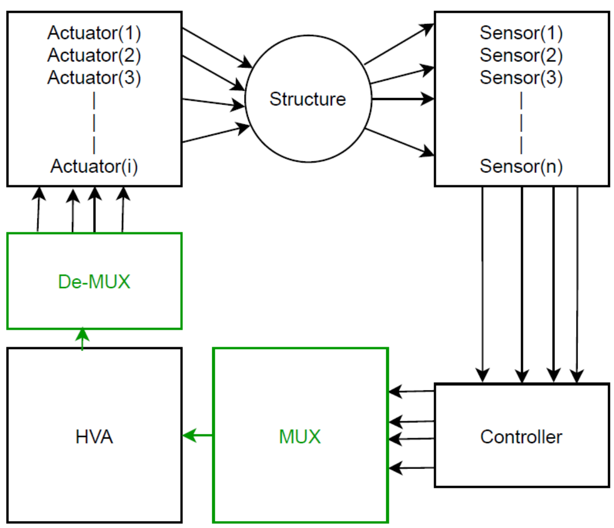

Figure 7: Reduced amount of amplifiers

1.5 Goal of the report

The goal of this report is to show the methods that are used to answer the research questions. This will help the overall research and usability of the information collected. Also, the research question will be answered in this report with their conclusions. The research questions are:

What hardware is needed to build a multiplexing setup for AVC?

What performance can be achieved with the now available hardware?

What is bottlenecking this performance?

The overall question will be as follows:

Proof that multiplexing can be a feasible solution to eliminate large numbers of amplifiers.

1.6 Structure of this paper

The structure of this report will be as follows:

- Introduction
  In the introduction, there will be explained how the project originated and a short story on what to expect from this report.
- Literature survey The literature survey section is where the papers are shown which are used as preliminary information for the thesis.
- Paper The paper is a brief explanation of the overall project which includes background, experiments, and conclusions.
- Conclusions In this chapter, the overall conclusion will be shown on the side of the future work.
- Recommendations This section will be helpful for the next student to research this topic.
- Self reflection This part is mainly for the supervisors and tells what the difficulties were in this project and what could be done better in terms of organizations or planning.

2 Background and literature

This chapter consists of knowledge found in articles and papers and is also showing a state of the art of this subject. It will explain structurally how things are involved for the problem stated in section 1.

2.1 Piezo electric transducers

A good place to start understanding this topic is the Piezoelectric transducers themselves. Such a transducer can generate a voltage by deforming the material. This material can have these properties by nature such as Quartz or the material can be designed for this by a polarizing treatment on ceramic material. The second option is used the most to make a sensor or actuator on the principle of the Piezoelectric effect. This effect is reversible, so you can also apply a voltage on the material, which causes the material to deform and this is used in AVC. The transducer electrically behaves like a parallel plate capacitor and mechanically as a spring with a stiffness.

2.2 Multiplexing

In looking for methods to reduce the amount of hardware for systems, the term multiplexing is commonly used. Multiplexing is a method that combines several signals into one signal, called multiplexing, does something with it, like transferring over a distance or amplifying it, and then extracts it again to separate signals, called de-multiplexing. Figure 8 schematically shows multiplexing. Multiplexing is mostly used with information signals by computers and telecommunication, but can also be used for actuation signals instead of data.

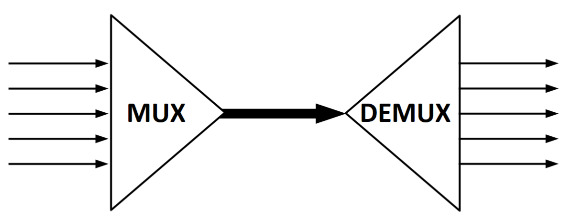

Figure 8: Schematic multiplexing

Multiplexing can be achieved in two ways, frequency division(FDM) and time division(TDM). For now, the TDM multiplexing in figure 9 is shown how these two methods can be defined.

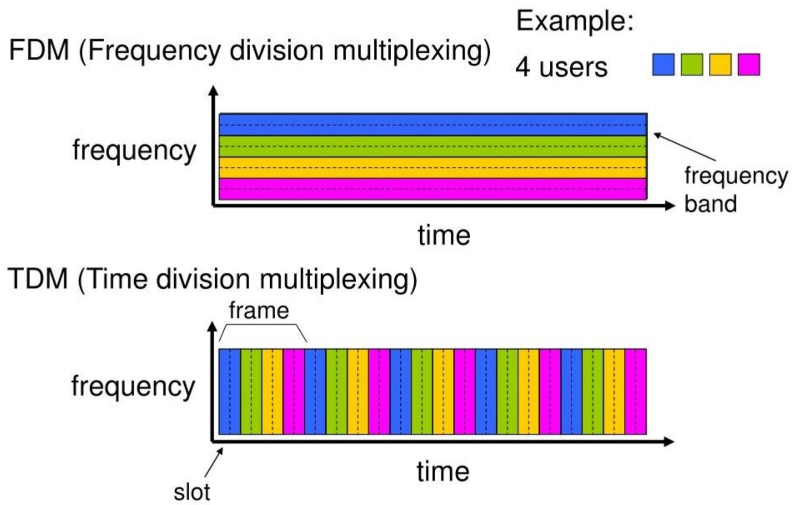

Figure 9: FDM and TDM [6]

Frequency multiplexing

In the upper graph, the method for FDM is shown. Frequency multiplexing is a method that uses carrier frequencies to transfer data and is using frequency modulation. This method is not used in the papers found about multiplexing with piezo transducers, so there is chosen to do this research only with the focus on TDM.

Time-division multiplexing (TDM)

TDM is a method that is used multiple times to reduce the hardware resources in systems as shown in the upcoming sub-sections. As seen in figure 9 it is a method that divides frames and slots over time. Each frame consists of a few time-slots. It is chosen that each time slot will represent one actuator. So when one frame is finished all the actuators were actuated. It can also be the case that each time slot contains multiple actuators but for now, this is simplified to just one. There exist two types of TDM, synchronous and a-synchronous TDM, where synchronous means that the time a slot takes is fixed and a-synchronous means that the time a slot takes is dependent on a factor in the system. This could be dependent on the frequencies that need to be controlled or the time it takes to calculate the next value.

2.3 Multiplexing used for active vibration control

Multiplexing can be used for sensors and actuators in active vibration control. As mentioned in [7] the performance lost is negligible in ideal situations. This article also describes the benefit of using multiplexing for sensors. It states that the computational time can be reduced by reading out just one sensor which is collocated to the that timeslot driven actuator. The paper also stated that multiplexing will work best with actuators that have capacitance behavior instead of inductive behavior. That is because of the electric energy stored in the actuator which will slowly decay when it is not driven anymore. Piezo transducers are actuators with capacitive behavior. This can be shown by modeling a RC-circuit which can be used as the electrical model for a Piezo transducer.

The paper shows a simulation in an ideal situation, so without the rise and decay of the signal. This simulation shows that the multiplex method works with almost no compromises. They stated that if the sampling rate will be higher the performance lost is negligible. It only ends with this conclusion and no further work is done in this paper.

Multiplexing with multiplex-theory-controller

It is also possible to change the controller so that it works more efficiently with the multiplexer. For this, the theory described in a paper from 2006 [8] can be used. This method is out of the scope of this report but must be considered in future work if performance is not achieved.

A paper from 2008 [9] shows the implementation of the method described in the paper from 2006 [8]. The focus here is placed on the multiplex control theory, which is used to develop an algorithm that is adjusted to a multiplexed system. The paper explains what hardware is used and how the experimental setup is built up. It doesn't show the difference in the performance of a conventional system against a multiplex system.

2.4 Multiplexing control for static application

A paper from 2005 [10] shows how multiplexing is implemented to drive a system that is used in adaptive optics. The deformable mirrors in this adaptive optics system are driven by piezo transducers and each of them needed an HVA. This paper shows how to drive such a system in a multiplexed way but doesn't win acceptance because of complexity in implementation. The performance of the system is not compared or called in this paper.

2.5 Conclusion

After the literature study, there can be concluded that this is a niche topic. Even the combination of multiplexing and piezoelectric transducers or even electrical loads is not researched much. One of the literature pieces found is about the placement of mirrors, so more of a static system, another one is stopped at deriving a model and the last one is stopped at deriving a setup.

Hardware sharing systems can be used in places where there are weight, volume, and heat limits, so for example space or temperature depending on machines. This is for now a hypothesis because there must be research if multiplexing could be a benefit for those factors.

Weight and volume will be reduced because the switches/relays are a fraction of the amplifiers, but on the other hand, it could be possible that the amplifier must be bigger. If times allow this is something that could be added to the scope to research.

The de-multiplexer is the state of the art in this kind of system. In [9] is decided to go with MOSFET photovoltaic relays. These can handle the higher voltage and switch relative fast to other relays which can handle this voltage. They mention the PVA13N specifically so this is the starting point for the hardware needed to build the setup.

3 Literature gap and contribution

From the information found in section 1 and 2 the following section will provide the literature gap and contribution in this field.

3.1 Literature gap

There are some gaps in the literature shown in 2 and this allows doing more research on this subject. The following questions will be the one that needs to be answered in this thesis.

- What kind of performance is achievable in multiplexing systems compared to conventional?
- What kind of restrictions and problems appear in the multiplex systems?

The sections from the literature survey show that different approaches to multiplexing are studied. It concludes that multiplexing is already be used in AVC-systems, one of them is from 1995 when computational power was playing a role, another has shown that it can be used for mirror placement in a telescope, so more of a static system and the last one shows that multiplexing used with multiplexing control, so designing the control algorithm with multiplex-control theory, works properly. The literature gap which can be found from this survey is that multiplexing with AVC is used but not in the most simple way with current hardware. So the goal of this thesis will be to show what kind of performance in AVC is achievable by just multiplexing the control signals without changing the controller.

3.2 Contribution

The results of this research will prove whether multiplexing can be used in AVC and if it is that beneficial in terms of performance lost in bandwidth compared to performance on other levels. So this will tell if it is worth time to investigate more in this concept. Also, an experimental setup is built which can be tested.

4 Methods

This master thesis is done by using simulations, programs, and physical materials. In the main part of this report, the state of the art, the paper, and the conclusions are discussed, but the work that is behind it is not presented here. This will be shown in the appendices.

4.1 Labview

The program used to drive and read the system is written in Labview which works together with the CompactRio. This process is shown in A

5 Paper

The next pages show the paper that is written for this master thesis.

Time division multiplexing combined with active vibration control

Tijmen Godfroid
High-tech engineering department at TU Delft

The high-tech industry is constantly searching for methods to make more efficient, more accurate and faster machines. One of the methods to improve the performance of these machines is active vibration control(AVC) which can help to achieve faster transients responses. One of the ways to achieve this is better controlobilty which means more actuators to control more modes. These actuators are mostly Piezo transducer in AVC and each group of actuators need a high voltage amplifier. At some point the number of amplifiers will be a limit, so if the group of actuators can share a amplifier, that would be beneficial. This can be achieved with time division multiplexing(TDM). This method in combination with AVC is researched in this thesis. most important aspects are performance comparison to conventional systems without multiplexing. First some simulation are done, to show that the TDM is a feasible solution, secondly a setup is build to check performance and validate the simulations.

I. Introduction

The statement "Moore's law is the observation that the number of transistors in a dense integrated circuit (IC) doubles about every two years" is about to end according to statistics [1], but the high-tech industry, especially semiconductor chip machine manufacturers, will keep on trying to design faster and more accurate machines.

One way to increase the performance of such machines is to decrease settling times, so faster transients, and that is mostly done by forced damping. In the frequency domain, this means lower resonance peaks, and the higher modes that can be damped, the higher the bandwidth of the system becomes. This can be done by passive damping and active damping, both have their pros and cons, but that is something that would be not be discussed in this paper.

The method which will be further considered is the active damping that is using piezo actuators. To test active damping with their control algorithms there will be used beams with piezo bender actuators attached. The beam is being disturbed by a known or unknown vibration, a sensor will sense this vibration and this will be read out by the controller. The controller uses an algorithm to calculate the damping signal that sends that signal to the actuator attached to the beam via an amplifier.

The piezo bender needs a high voltage amplifier and this is where this paper will be interesting because by increasing the number of actuators, the performance of active damping systems will also increase because of controllability. Each group of actuators needs its high voltage amplifier because most of these piezo actuators work in orders of 10^2 to 10^3 volts.

The introduction of large numbers of amplifiers can cause problems or unwanted characteristics. It can cause for example higher masses, less efficiency in terms of heat or energy consumption, and more volume in such systems. These characteristics will not be researched but the problem that will be researched is to find and test a solution to use only one amplifier for multiple groups of piezo actuators.

To tackle this problem multiplexing is being chosen, especially time-division multiplexing. Multiple solutions were considered, like frequency division multiplexing, but from the literature, the time-division multiplexing seems the most promising. This is a method that is commonly used in telecommunication to transfer data over one line instead of multiple lines. These data transfers are done with very small currents and voltages at really high speeds, talking about Mhz. To use this method for power electronics, especially active vibration systems is not much research yet. The research that is done on this topic is shown in the next sections.

A. Multiplexing used for active vibration control

Multiplexing can be used for sensors and actuators in active vibration control. As mentioned in [2] the performance lost is negligible in ideal situations. This article also describes the benefit of using multiplexing for sensors. It states that the computational time can be reduced by reading out just one sensor which is collocated to the at that timeslot driven actuator. The paper also stated that multiplexing will work best with actuators that have capacitance behavior instead of inductive behavior. That is because of the electric energy stored in the actuator which will slowly decay when it is not driven anymore. Piezo transducers are actuators with capacitive behavior.

The paper shows a simulation in an ideal situation, so without rising and decay of the signal. This simulation shows that the multiplex method works with almost no compromises. They stated that if the sampling rate will be higher the performance lost is negligible. It only ends with this conclusion and no further work is done in this paper.

B. Multiplexing with multiplex-theory-controller

It is also possible to change the controller so that it works more efficient with the multiplexer. For this, the theory described in a paper from 2006 [3] can be used. This method is out of the scope of this report but must be considered in future work if performance is not achieved.

A paper from 2008 [4] shows the implementation of the method described in the paper from 2006 [3]. The focus here is placed on the multiplex control theory, which is used to develop an algorithm that is adjusted to a multiplexed system. The paper explains what hardware is used and how the experimental setup is built up. It doesn't show the difference in the performance of a conventional system against a multiplex system.

C. Multiplexing control for static application

A paper from 2005 [5] shows how multiplexing is implemented to drive a system that is used in adaptive optics. The deformable mirrors in this adaptive optics system are driven by piezo transducers and each of them needed a HVA. This paper shows how to drive such a system in a multiplexed way but doesn't won acceptance because of complexity in implementation. Performance of the system is nor compared or called in this paper.

This comes to the goal of this project, to check the feasibility of the multiplexing combined with the active vibration system with the piezo transducers. This will be done by checking performance in the frequency domain. First, there will be done simulations in Simulink and Matlab and second, there will be built an experimental setup to do several tests on.

II. Background

A. AVC use and control algorithms

Active vibration control(AVC) is used to damp materials faster so that machines become faster and more accurate. Also, there is the phenomenon fatigue, which can occur when a material keeps on vibrating and never stops because it lacks damping. This is something that happens in space because there is no air and vibrations can go on forever.

To go from vibration control to damping some control algorithms are required. These algorithms are tuned so that they control certain modes, where the resonance peaks originated. The algorithms ensure that the peaks at these frequencies are en-lowered. Commonly used control algorithms in AVC are Integral resonance control(IRC), direct velocity control(DVF), and positive position feedback(PPF). This paper is not going in-depth into these algorithms, but they will be used to explain certain thoughts about AVC.

B. Feedback Loop

The figure 1 represents a feedback control loop, in which an algorithm is implemented and will be described by the 'controller'. The 'amplifier+actuator'-block is the part on which this thesis will be focusing. These actuators are commonly piezo electric actuators, as well as sensors. This means that for example DVF is not preferred in AVC systems in combination with piezo transducers, because the piezo signal is a position signal which needs to be integrated and this causes a different kind of limitations for the performance.

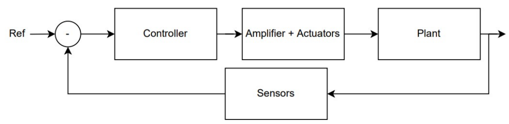

Figure 1. Feedback loop

C. Conventional figure of AVC

The figure 2 shows a AVC system which focus more on the Kc(s) part, you see here the controller, high voltage amplifier(HVA) and the actuators.

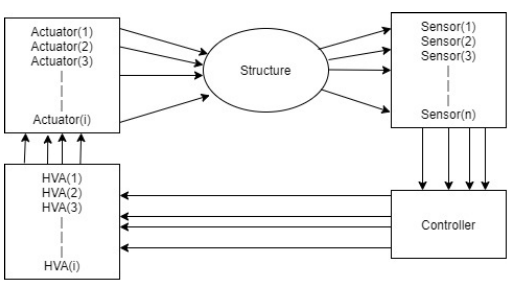

Figure 2. AVC system focus on Kc(s)

D. HVA's

What also can be seen from this figure is that there is a HVA for each actuator. Each actuator or actuator-group for each mode needs its own amplifier because the signal sends for each mode is different, but can happen at the same time. A beam can have infinity modes, and to design for example a system with perfect actuation and perfect sensing or even over-actuation and over-sensing, you need to have at least one sensor and actuator for every mode in the system.

So at some point, there is a limitation, and this limitation starts with the amount of HVA that can be used. HVA's have a high mass , and high volume, consume a lot of energy and create a lot of heat. So if there is a way to reduce the number of amplifiers, this would cancel this limitation, and systems can perform better.

III. Active vibration control combined with multiplexing

A. Synchronous time division multiplexing method

The method used in this thesis project, so the boundary will be the synchronous time division method(TDM). This means that the time a signal is sent to an actuator or group of actuators will be the same every time for every actuator. This directly follows with a multiplex frequency, which is the frequency of the square wave which activates the relays. Another option for TDM is a-synchronous, which means these timeslots can change over time or with every actuator, but this can be considered in the following research. The multiplexer method exists of a multiplexer-part and a de-multiplexer-part as shown in figure 3. It is important that the multiplexer and the de-multiplexer work at the same clock. To individual signals are now

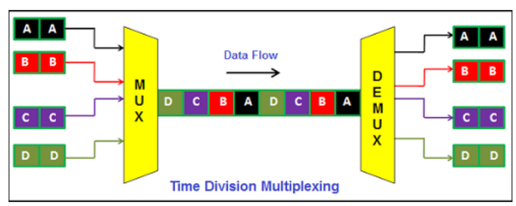

Figure 3. Multiplex method[6]

divided in timeslots, as shown in figure 4.

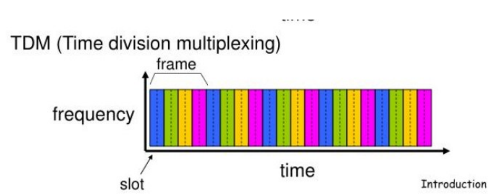

Figure 4. Timeslots[7]

B. Simulation parameters

The simulation needs some parameters, they are used for the physical system that is modeled and for the simulation itself. The most important one is the multiplex frequency and the frequency on which the structure should be controlled.

1. Multiplex frequency

The multiplex frequency is the rate at which the relay switches so that one of the actuators can be driven at the time. The switching rate is dependent on the performance of the relay used for the de-multiplexer and also on the voltages, it needs to switch. With higher voltage, there is a higher reach time for the relays. So this parameter can be tuned during the experiments. The start value will be the given value from the datasheet from the relay.

C. Structure frequency

The structure will be a physical object with some modes. It is important that these modes can be damped. For now, a frequency from 1hz to 1Khz is chosen, since this is a very common mode frequency for stiff structures.

D. Simulation

Multiple simulations are done, first there will be simulated what the signal will look like, which is send to the amplifier. The following simulations includes a low pass filter(LPF) model, because a LPF commonly used to model a piezo transducer. In this thesis, the focus will not be on the control part, but there can be assumed that a control signal will be having the characteristics of a sinus signal. So a sinusoidal wave will be used in the simulations and experiences.

1. Simulation 1

The first simulation is one that shows what the signals look like. This helps determine on what kind of solver and what kind of step-size the simulation needs to run. Two signals are multiplexed and shown in figure 5. The simulation is done in Simulink and built in the

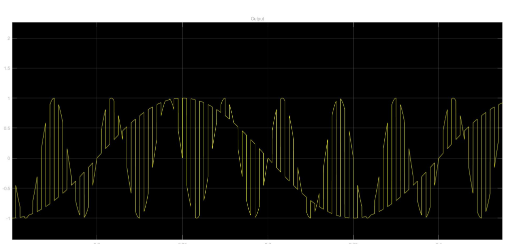

Figure 5. Multiplexed signal

conventional environment. We can conclude for this step the stepsize and solver are not that important.

2. Simulation 2

The next step is to de-multiplex the signal and send it to the LPF-model. This LPF could be made from a transfer function in the conventional environment, but it isn't possible to just break a signal since that will bring the signal to zero, so ground, and that is not what we want. Therefore there is a switch to the electrical environment with a resistor and capacitor to build an electrical circuit. To build the de-multiplexer a single-pole relay is chosen which can be driven by a pulse. First, there is chosen to go from a chirp signal to the relay, so no multiplexing is involved, the model is shown in figure 6 The effect on the low-pass filter,

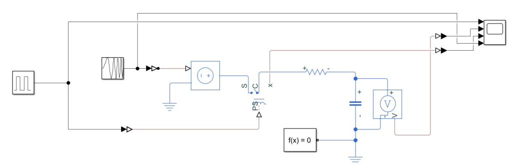

Figure 6. 1st electric circuit

capacitve behaviour is really noticeable, when the circuit breaks because of the relay, the figure shows that the capacitor hold there charge, so there voltage, which is expected.

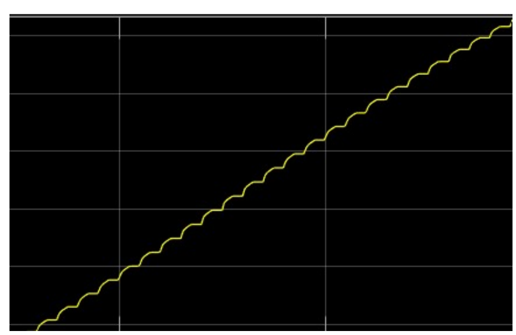

Figure 7. Effect

3. Simulation 3

The next step is to multiplex the signal before it is send to the relay. If the the system is ideal this wouldn't make sense, but a system can't be ideal. So the circuit is changed to figure 8. Since the pulse is now used

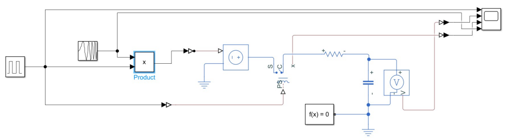

Figure 8. 2nd Electric circuit

for both the multiplexer and de-multiplexer they need to be synchronized and also have the same rise, but as shown in figure 9 the pulse that coming from the read-out from the relay is slightly having a rise and decay. This is not because the relay is not modeled ideal, this is because of the solver and the stepsize but it is something that also can happen with the real relay in the setup later on. Because of this rise, there will

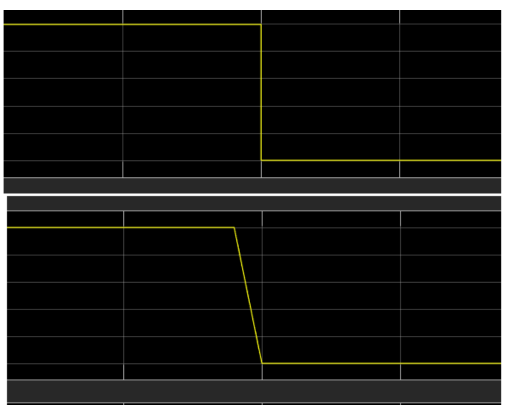

Figure 9. Pulse-signal

be an overlap between timeslots, which means with one signal which looks like one of the signals in figure 13, so not combined as in figure 17, the signal will be pulled to the ground which means the capacitor can discharge. This is an unwanted event and causes the signal to look like this in figure 10, which means energy is lost, and so performance will drop.

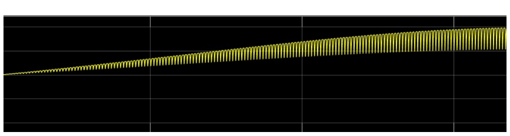

Figure 10. Unwanted grounding because of overlap

E. Margins

So from the simulations, we learn that overlap is an unwanted event. Margins are needed because of the response time and slope of the relay. These margins are added to the last electrical circuit simulation why insert a delay in the pulse signal and change the duty cycle. It depends on the performance of the relay what these values will be, so this is later discussed.

F. Conclusion

From the simulation, it can be concluded that multiplexing could be a feasible solution to reduce the number of amplifiers. Therefore a setup will be designed to validate the simulations and this conclusion.

IV. Validation

A. Plant

A setup for experiments to validate the simulations and the theory is built. The plant of this setup will be two beams with piezoelectric transducers on both sides, one acting as an actuator, the other as a sensor. These structures will be actuated separately on different frequencies with the same amplifier with the help of multiplexing. One of the beams used is shown in figure 11 on which the piezo transducers are attached. Since the experiments are comparative, the position of the actuators and the sensors are not important.

B. Experiments

The goal of the experiments is to show that the simulations make sense and that the datasheets of the hardware gave correct limits. Also, there is looked for inconvenience behavior of the hardware which is not thought of before.

1. Relay performance

According to the data sheet, the response time is 60 to 100us and the slope is 1000V/us. But from the tests, there is concluded that the complete time the relay signal has settled takes around 1ms. But these values are dependent on the signal it needs to switch, so voltage and current.

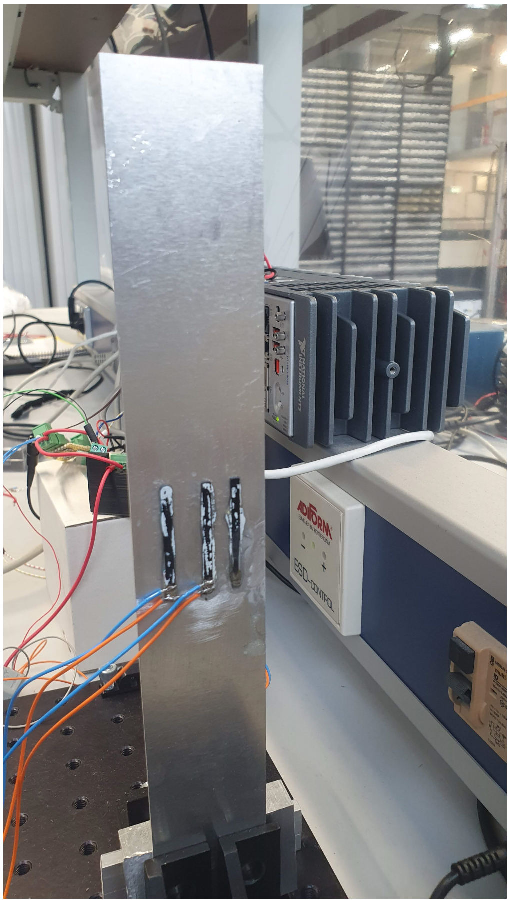

Figure 11. Beam as structure

2. Identifications

Identification is needed on the structures to get a baseline and to check if there are no issues with the initial setup. A sweep signal from 5hz to 350 throughout 90 seconds is used to identify the setup. This experiment is conventionally, so without any of the multiplexing integrated. The time data will be used to create a frequency response function with the help of the "tfestimate"- function from Matlab.

3. Synthetic test

The synthetic test is important to check the reaction of the plant to a sinusoidal signal that is multiplied by a block-signal, shown in figure 13, because from this test there can be concluded that the structure behaves as the simulation and that the plant has capacitive behavior. The test is done the same as the

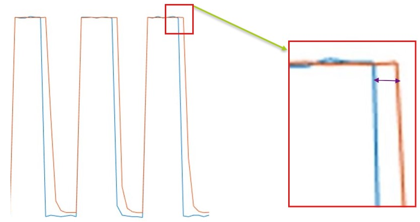

Figure 12. Switch characteristics

identification test, from the sinusoidal signal before the multiplexer to the sensor output of the plant. The hypothesis was that the signal will be grounded

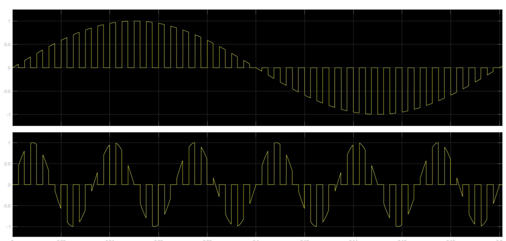

Figure 13. Block signal multiplied with sinusoidal

every time the block signal is zero so that there is a gain-loss of 50% which concludes that the piezo transducer has the same characteristics as a capacitor.

4. Multiplexer test

The de-multiplexer, part of the multiplexer method, will consist of multiple relays. The performance of these relays is very important and is described in the datasheets of the relays. Although the datasheets are well described the performance must match the situation they are going to be used. There the relay performance will be tested during the experiments on reaction time and rate. As described in figure 14 the $t_d ly$ is the reaction time and $t_o n - t_d ly$ will describe the rate and that time is dependent on the high of the voltage.

5. Performance test

The performance test is done with the de-multiplexer included, so this means the signal, a sweep-sinus, is multiplexed in the CompactRio, amplified, and then de-multiplexed with the relays. The two structures

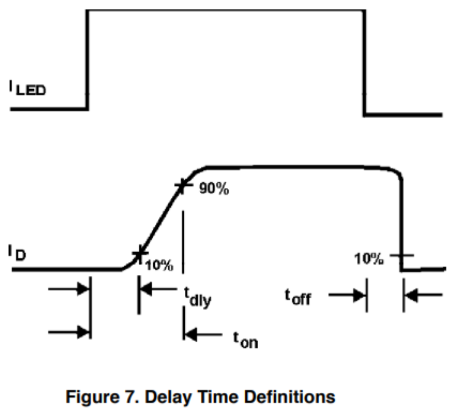

Figure 14. Relay characteristics

will be active at the same time, one of the structures will be driven with a constant sinus wave and the other will be driven with a sweep. This is to show that there is no interference, which can be checked in the frf of the experiments. The frequency at which one of the structures is driven is at the first mode frequency of the structure which is driven by the sweep. In this way, if there is any interference, it will be noticed.

C. Setup

The setup build is shown in the scheme in figure 15 and shows the electrical components which will be further explained in the next section.

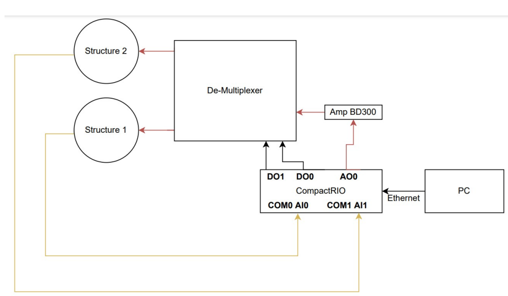

Figure 15. Setup

D. Electrical components

1. De-multiplexer

As described the de-multiplexer is part of the multiplexer method and consists of two relays. These relays, the PVA30NPbF, are wisely chosen for their switching time and maximum current handling.

2. Amplifier

The amplifier used in this setup is the BD300 from Piezodrive, it is a dual-channel driver if used without negative voltages. In this case, one channel will be used but only for a positive output, since the piezo elements are configured that way on the aluminum beams.

3. Compactrio

A Compactrio as DAQ-system is needed because the analog and digital outputs, needed for the multiplexing method can be synchronized. This synchronization is needed because the time that the signal must be multiplexed and de-multiplexed must happen at the same time, so there will be less interference. Of course, there will be some latency because of the components such as the amplifier, but these can be included in the time margins as fixed data.

E. Software

Labview The software used to send and collect t the data is Labview. A LabVIEW programmed environment is the multiplexer and multiplexed the two sinusoidal sweep signals together to one. That signal looks like the signal as shown in figure 5 and is outputted from the analog module to the amplifier.

F. results

So the graphs of the different experiments are in the following sections.

1. Identification

The frf of the identification of structure 1 is shown in figure 16. Two modes are clearly shown and the gain and phase are the values that can be compared with the multiplexed systems.

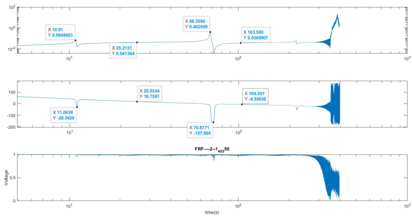

Figure 16. Identification

2. Synthetic test

The synthetic test, so where one of the timeslots is pulled to the ground shows an frf with a gain-loss of 50% over the whole frequency range. This corresponds to the theory that the piezo-transducers behave as a low pass filter, so it proves that it has one of the characteristics of the LPF.

3. Performance

By comparing the FRF of the multiplexed system. shown in 17, to the identification FRF the performance can concluded. We see here the graphical

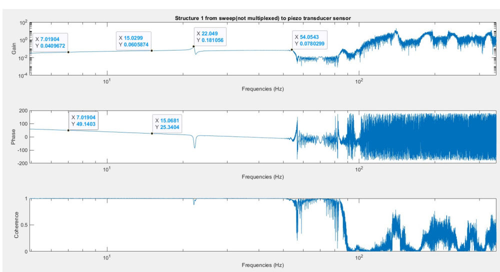

Figure 17. Multiplexed structure 1

comparison of the gain at certain frequencies between the conventional system and multiplexed system.

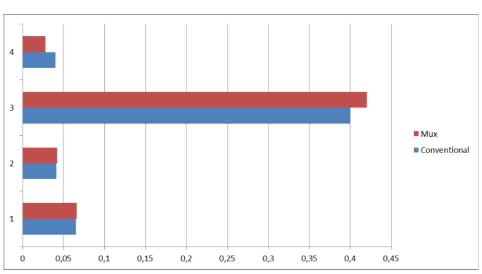

Figure 18. Comparison

G. Conclusion

The overall conclusion of the validation is that the setup works as it should and that the bottleneck of the methods is the on/off-time of the relay. The faster this can switch the higher the bandwidth, so the performance will be.

V. Conclusion

The goal was to getting known with the subject TDM in combination with AVC and to check if it may be a feasible solution to reduce the number of amplifiers in a AVC system. We succeeded to simulate the process and create a experimental setup where the TDM is executed on a AVC system, with negligible performance lost in a certain bandwidth. The bottleneck of the bandwidth is the relay-performance and if this could be improved the solution could be a success.

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6 Conclusion

From the setup and simulations conclusions can be reached about performance and feasibility.

6.1 Performance

Performance is now bottlenecked by the relays in the de-multiplexer that cannot switch faster to achieve higher control frequencies. It is shown that the multiplex frequency is dependent on the performance of the relay. The higher the multiplex frequency the higher the bandwidth. So when this is still a bottleneck, there could be not be made conclusions on the an ideal multiplex frequency. For now the conclusion is that the higher the multiplex frequency, the higher the bandwidth. And this highest frequency could be found by tuning it till the gain reduces.

6.2 Feasibility

For structures with modes below 50 Hz and just two actuators the multiplexed system will work. If this is a frequency which could be worked with in a structure than this is a feasible solution. In the section future work there will be explained what work needs to be done to check further expansibility.

7 Future work

7.1 Recommendations

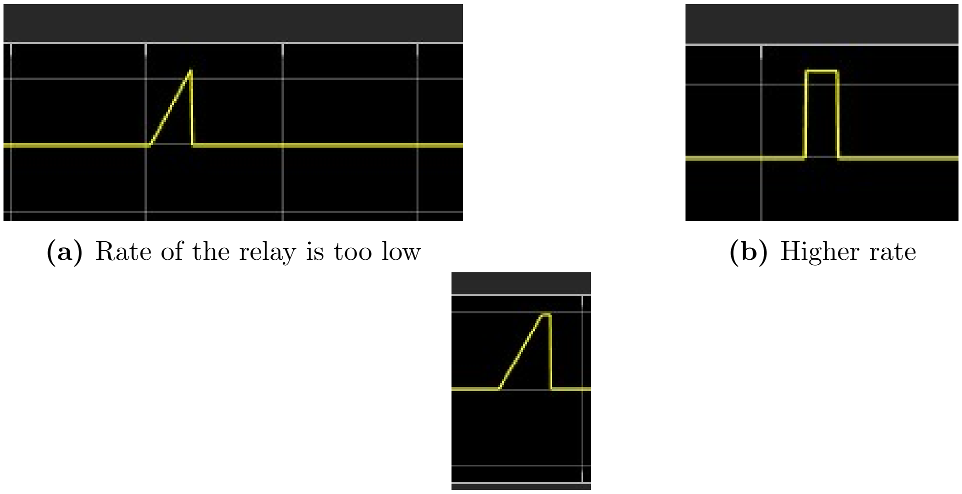
As mentioned in the boundaries of this thesis, the multiplex method used is synchronous method and not a time-varying one. This is something that can make this method efficient and should be researched.

7.1.1 Phaseshift

Most of the research was focused on the gain and not so much on the phase-shift. Despite that there can be seen on the frf that the phase isn't significant changing, it could be further researched when multiple actuators will be used.

7.1.2 Expansion of the system

The number of actuators could be extended which means the duty cycle will be smaller per actuator. The effect to change to this duty cycle must be researched. Also is this limit dependent on the the relay switch frequency. If it could switch faster, the margins could be smaller, which means higher gains. At same point with multiple actuators attached to the system the duty-cycle becomes so small that the on-off time is in the order of magnitude as the time that the actuator is driven.



(a) Rate of the relay is too low

(b) Higher rate

(c) Higher duty cycle, so less actuators

Figure 10: Problems occur due to more actuators

8 Self-reflection

When I did the planning for this project I was naive in the time it takes to get the experimental setup getting to work. The first DAQ-system I used in the beginning was not sufficient, I had asked for help, but this was something that was undone by the staff, so this brought me to a faulty system. It took a lot of time to find out that this was the problem. With the second DAQ-system, which was sufficient I had spend a lot of time to get the program written in labview working on the DAQ-system. With no experience with the CompactRIO at all, it took a lot of time to figure it out.

Due to the complexity of the CompactRIO and the electrical system in my system which is harder to understand for mechanical engineers it took a lot of self-learning. This went fine but was not a straight forward process. So I grow as a researcher and have more knowledge of electronics than before.

Also the time in the lab learns me to work with devices which I had never touched before, which made me also enthusiast in an other field than mechanical engineering, electrical engineering. Devices as the oscilloscope are very use full and will help me in future projects to tackle problems.

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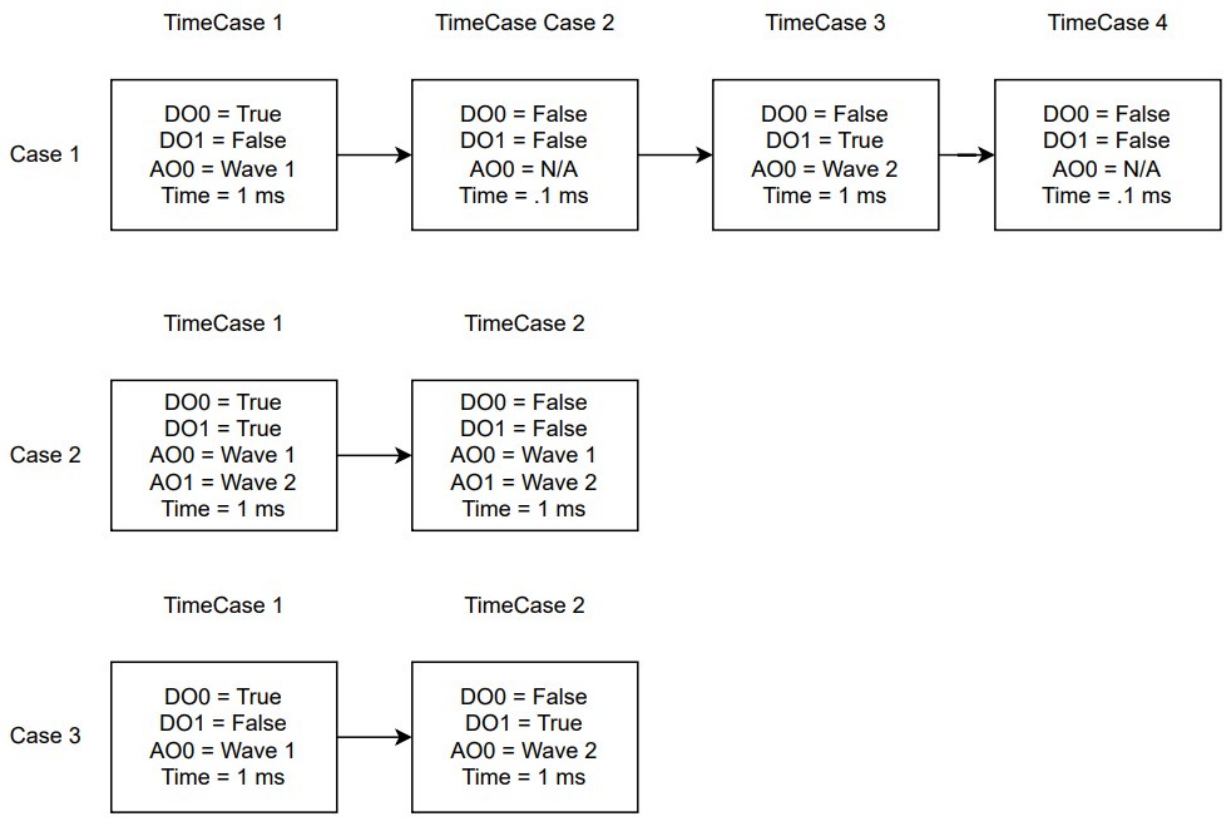
A Labview and CompactRio



The labview program is build up in 3 layers for the CompactRio:

Host, this is the program that runs on the operating system(OS) of the PC and can ask the Realtime system from the CompactRio for information and send information. This is the place where the graphs are shown and the data is send to a file which can be later analyzed.

Realtime, that is the part that runs on the OS of the CompactRio. This communicates between the PC and the FPGA-chip(which is the last layer of the program). It can be reached real-time, as the name already predicted.

FPGA, this is the chip in the CompactRio that can be programmed and work really fast without any disturbances. It can't be reached during run-time but it sends the data to the real-time program.

For all these layers there need to be a program written in LabView. The most important one that drives the actuators and switches is the FPGA-chip that is directly connected to these in and outputs.

Multiple experiments, so programs are done, which can easily be done in Labview by building cases. 3 of these cases are shown below. First case is the one with the time margin, second case is one where wave-signal keeps being send to the analog output, but the switch is turned off, case 3 shows that wave 1 and wave 2 are alternating respectively as the digital outputs.