Swept Optical Delay Generator

Group B

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Significant Contributors

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Customer and Sponsor

Harris Corporation

Individual Group Member Motivation

Marcus Darby

Being the only member of the team who is not an optics major working on a primarily optics project allows me to gain more experience in the optics field, which is something that has interested me for some time. Being on this team will allow me to use what I have learned as an electrical engineer and apply it in a way I may not have otherwise done.

This project also gives me the opportunity to understand how to design and use a microcontroller to fit the given requirements for our design. Previous courses have allowed me to understand just how to build and design circuits for a desired output signal. In the scope of this project, however, I need to understand how the microcontroller will work in tandem with the motors or any other connected parts. Thus I will need to first understand the properties of the signals that are desired and then figure out the best approach to implement such a signal.

Overall this project is desirable for me by taking me outside of my comfort zone, allowing to learn and understand optics, a discipline that has similarities with yet is different than my own, while also working on an aspect of my own discipline I am not entirely experienced with. Being able to learn and adapt to these objectives will give me confidence that I can adapt to any situation and problem that I may have to face.

Kevin Gaj

With my majors being electrical engineering and photonic science, this project presents a great opportunity to apply my knowledge of both areas into one design. I will gain experience in both fields. Also, I am looking into a future career in the defense field, so this project could give me good experience in that area since it will most likely have some sort of military application.

In addition to the above, this project will be a great opportunity to see how both of my majors can tie together in a final system. Usually my classes focus on just the electrical engineering aspects of a project or just the photonics/optics aspects of a project; however, now I can see how both sides are equally important in the design, development, and function of a final system.

I have had an internship that was focused on electrical engineering design, but I have been wanting to also gain some industry experience in the field of optics. Although not directly in the industry, this project is funded by a major corporation, and it involves working with industry professionals. I feel this will be a good opportunity to give me some idea of what it is like to work in the field of optics in industry before I graduate from school.

Samuel Nunez

As an optics and photonics engineer, this project presents an opportunity to gain knowledge and experience in designing and perfecting an advanced fiber optic communications system. This project presents challenges from a theoretical geometric optics approach as well as real engineering issues regarding optical engineering components.

Personally, fiber optics communication systems at photonics processing systems for electronic warfare and communication has been of great interest to me throughout my academic career. This project provides the opportunity to work on an exciting topic with some of the leaders in the field at Harris Corporation.

Another personal motivation is the chance to learn and improve upon electrical engineering and coding skills. Although my contributions to the topic will be largely related to optics and photonics, due to the nature of the project it is also likely that I will be able to gain experience with some of the topics I have learned in general electrical and computer engineering courses.

Caleb Stephan

With my major being Photonic Science and Engineering, I wanted to do a project that was heavily optics based. Every since taking geometric optics, the methods of directing, bending, and manipulating light has interested me very much. The applications of various optical systems have been very fascinating to me, and I want to learn what it is like to actually design an optical system.

This project will give me an opportunity to apply concepts and principles I have learned from my academic studies to a real project. Personally, I learn best by doing, so working with optics and optical systems will aid me in learning more about my field of study. I am excited to see how things on paper meet real world application.

Another motivation for me personally is that I am very interested in increasing my experience with research, design, and testing. I have very limited experience with these disciplines in the past, and this project will have me to engage in all three. I am motivated by this project because it gives me a taste of what industry will be like, since we are working with Harris to attempt to provide a system that will be of use to them. Overall, this project will stretch me in my knowledge and allow me to gain valuable skills that will be useful to my career in industry.

Sponsor Motivation

The sponsor is responsible for designing and constructing a complex RF photonics processing system comprised of multiple optical processing components. The optical delay generator discussed is one of these components. Initially, the sponsor had taken a different approach than what is suggested here, using a frequency swept source and chirped fiber Bragg grating to generate the delay. This system, however, is not compatible with the overarching system due to the frequency swept nature of the source. The sponsor is interested in a continuous wave, frequency stable solution to this problem.

Another approach pursued by the sponsor was a circular multipass optical cell. The delay time of this system would be dependent upon the incident angle of the incoming light. However, the sponsor found that this approach yielded several issues regarding the total optical path length as a function of incident angle. Our project is to design a variable optical delay that overcomes the issues encountered by the sponsor while still meeting the requirement specifications of the system.

The option for Harris Corporation to simply purchase a variable delay line off the market is not an option for this system. As discussed in the requirement specifications section below, the specifications of this system regarding delay resolution, maximum delay range, ramp time, and intrinsic delay are fundamental to this project's future incorporation into the overarching photonics processing system designed by Harris.

Typical variable optical delay generators on the market today provide delays of hundreds to thousands of picoseconds. The resolution of these delay generators is typically determined by a manual micrometer.

These metrics do not meet the requirement specifications detailed in the section below. Furthermore, most of these delay generators are manually operated. The requirement specifications given by Harris Corporation require the final system to operate within fractions of a second. Therefore, the final system must operate automatically and will likely require the use of microcontrollers to achieve the final goals for the project.

Technological Motivations

Due to the proprietary and classified nature of the overall photonics processing system in development by Harris, specific knowledge regarding the overarching photonics processing system and how this project would be used for it is unavailable to our group. However, in this section possible motivations and uses for variable optical delays are discussed.

In terms of communications, variable optical delays are of high demand in regards to phased-array antennas. Phased array antennas are comprised of multiple, sometimes hundreds or thousands, of individual antenna elements. The maximum radiation in a particular direction is then controlled by the phase difference between the antenna elements [1]. This phase difference creates constructive or destructive interference, and depending on the degree of interference the direction of maximum radiation is changed.

Optical fiber is being used more frequently in phased array antenna systems due to advantages such as its relatively lightweight and has low losses [2]. Selecting the precise phase shift based on wavelength selective time delay elements has been a topic of discussion in this field [2]. One possible use for this project could be to act as a wavelength selective time delay element in a phased array antenna.

Project Description

The goal of this project is to design a rapidly swept optical time delay generator to be used in an overarching RF photonics processing system. In the final system an RF signal is detected, processed optically by various elements of the system, and the processed signal is then converted back into RF and emitted. This information was given by our sponsor. Our task is to design this swept optical delay generator as one of these optical processing elements.

The final goal of the project is to have a high degree of precision and control over the delay time, including the ability to specify and select discrete delay times at a rapid rate. Currently, there are two design approaches that are being reviewed and studied.

One design approach under consideration is to design an optical cavity with variable distance between the walls of the cavity such that the optical path length - and therefore the time delay - would increase. The cavity used would likely need to be folded multiple times in order to allow for a reasonable distance and number of components, as well as a feasible motor speed and precision.

We have considered a few options that could possibly achieve. The first is a corner cube mirror approach. This would involve setting up a line of corner cube mirrors that reflect the light back and forth (tracing the light rays would show a square wave pattern) to create delay. This will give us great freedom with the intrinsic optical delay. In order to vary the delay, we would need a motor attached to one line of corner cube mirrors to translate the mirrors further away from the opposite line of corner cube mirrors thereby increasing the delay. This method is fairly simple, and has plenty of freedom, but the precision and speed of the motor is a very big limitation to this method.

Another option with an optical cavity is making use of a Herriott cell. The basic concept of a Herriott cell is an optical cavity with two curved mirrors that has a single opening for the light to enter and exit. The light gets trapped in the cavity by getting reflected many times, and then finally leaves out the same opening by which it entered the cavity. To create a variable delay, we would have to change the location of one or both of the mirrors by using a motor. The main drawback to this method is there is limited resources available on this type of cavity, so it will be difficult to learn more about it without having access to a Herriott cell and performing extensive testing with it. Motor speed and precision are also a limitation with this method.

Some objectives involved with this design approach include designing the cavity such that the delay can be adjusted appropriately, implementing and controlling a motor to precisely and rapidly manipulate the size of the cavity, and designing the appropriate lens systems to allow for efficient free space coupling into fiber after the optical cavity. If a design approach using multiple mirrors is chosen, cost becomes a significant factor for this design approach.

Another design approach under review is based on serrodyne frequency shifting. This serrodyne frequency shifting method is a well understood technique based on linear phase shifting. A phase modulator is implemented and driven in a linear fashion by a voltage source. The slope of this line determines the frequency shift of the incoming signal, so different slopes would result in different frequency shifts.

A linearly chirped Fiber Bragg Grating could then be implemented to generate a delay based on the frequency of the incoming signal. Thus, an approach similar to the chirped Fiber Bragg Grating approach explored by the sponsor could be implemented while using a single wavelength source.

Some objectives involved with this design approach include finding the appropriate voltage source and phase modulator for this system. There is a trade off to be made between the maximum Vpi of the phase modulator and the resolution of the voltage source that determines the slope of the phase modulation and therefore the frequency shift of the signal. Typically, phase modulators can be relatively expensive, and the cost of the voltage ramp may be high as well. Therefore, comparing the cost of the two approaches will be crucial.

Requirement Specifications

In this section, requirement specifications are discussed. These include any specific constraints provided by

The main constraints for this project are related to the generated delays. The target delay range is from 1 to 2 nanoseconds, with step sizes of approximately 10 picoseconds. Harris Corporation has not given any requirement specifications in terms of an exact delay range. The only requirement in this area is that the final delay range of the system lie within the specified range.

The target time spent at each step of the delay is approximately 50 microseconds or less. The total transition time is required to be 50% of the time spent at each delay step or less. The ramp period of the system is approximately 10 ms, and the target intrinsic delay is approximately 1 nanosecond.

The size of the system is a fairly flexible constraint. The customer has expressed interest in the system being confined to a 1 foot by 1 foot space, with the potential of reducing space required.

Power is not a major concern of the sponsor, but a soft constraint of 30 Watts for the system, including the source and motor, was discussed.

Design Parameter	Target	Description/Notes
Max Delay Range	1-2 ns	This sets the total maximum path length of the system
Intrinsic Delay	1 ns (more if necessary)	Shortest possible delay through the entire system
Delay Step Size/Resolution	<10 ps	Maximum difference in delay time between steps
Delay Step Duration	<50 μs	Maximum allowable time spent at one delay. Derived assuming linear profile.
Max Delay Step Transition Time	Less than 50% of the Delay Step Duration	
Ramp Period	10 ms	
Ramp Duration	≤ Ramp Period	
Delay Ramp Sign	+ and -	
CFBG Dispersion	TBD	Only applicable with serrodyne approach
CFBG Apodization	Hanning	Only applicable with serrodyne approach

Table 1: Requirement Specifications

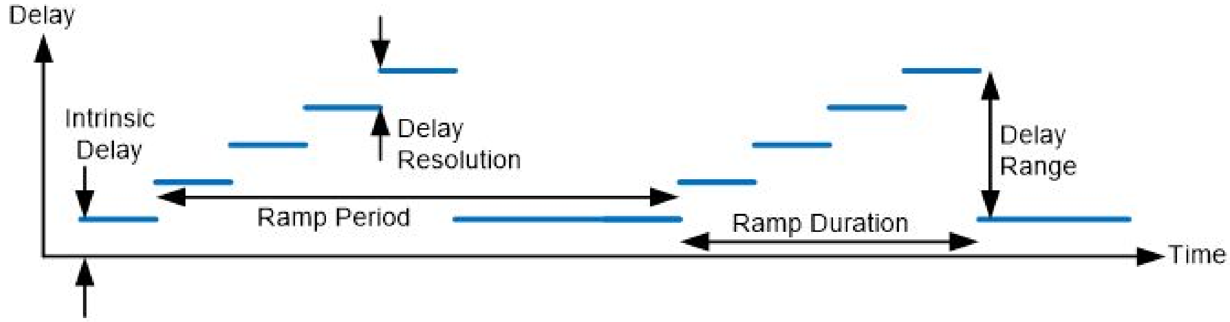

Figure 1: Visualization of Target Delay as a Function of Time

*Figure 1 provided by Harris

Traditionally, an optical delay line involves a single, long bundle of fiber optic cable in which the optical signal is allowed to travel for a given period of time to produce the delay signal. An RF signal will enter the unit and convert to the optical domain. From here, the signal will travel through preselected delay fiber paths and produce the built in delay for the chosen path. The signal is then converted back to the RF domain. Figure 1 shows an example of a typical optical delay line used for RF purposes.

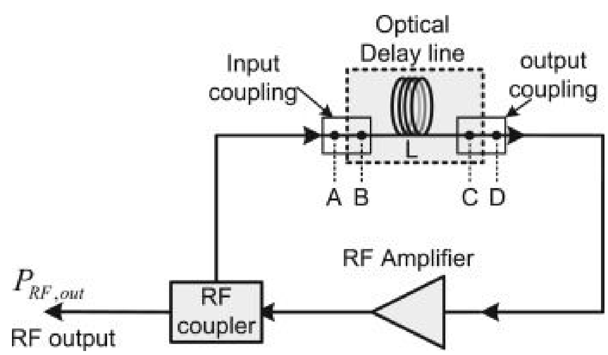

Figure 2: Traditional optical delay line

The problem with this approach for our design is that the intrinsic delay would be too high if running through a single, long fiber. In addition to this, the multiple steps of delays would require multiple fiber paths that each produce a greater delay than the previous fiber. In our design, it is possible that there could be hundreds of delay steps. It is not feasible or cost efficient to design a system that would require hundreds of separate fiber cable delay lines.

Since the traditional methods of using an optical delay will not work, a new system must be developed that can delay an RF signal optically while still following the design parameters. Whatever method is used to achieve this must ensure that the intrinsic delay requirement is satisfied, otherwise traditional delay line methods could be achieved.

Block Diagrams

<u>BLOCK DIAGRAM KEY</u>
Red box: Caleb, Sam, and Kevin
Purple box: Caleb and Sam
Orange box: Kevin and Marcus
TBA: to be acquired

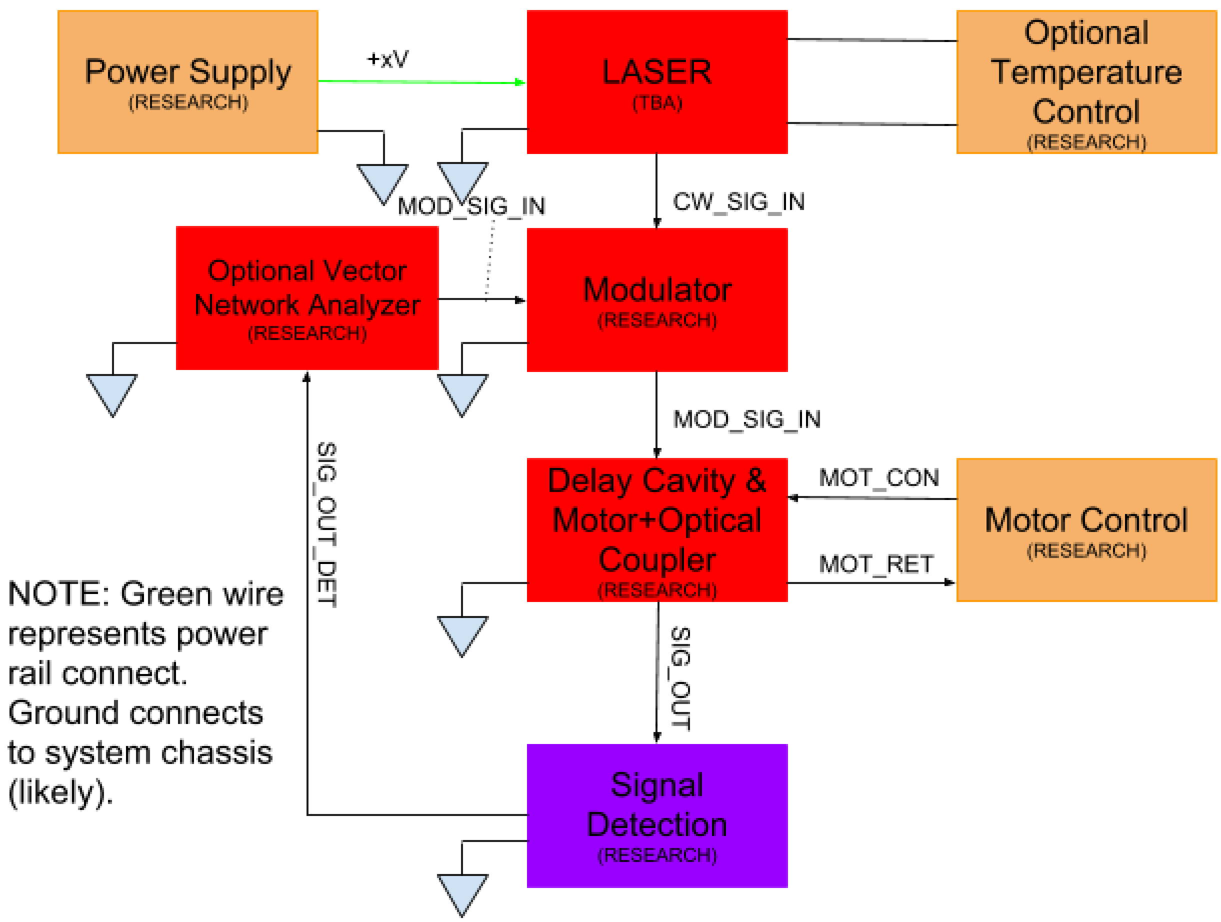

Figure 3: Block Diagram for Optical Cavity Approach

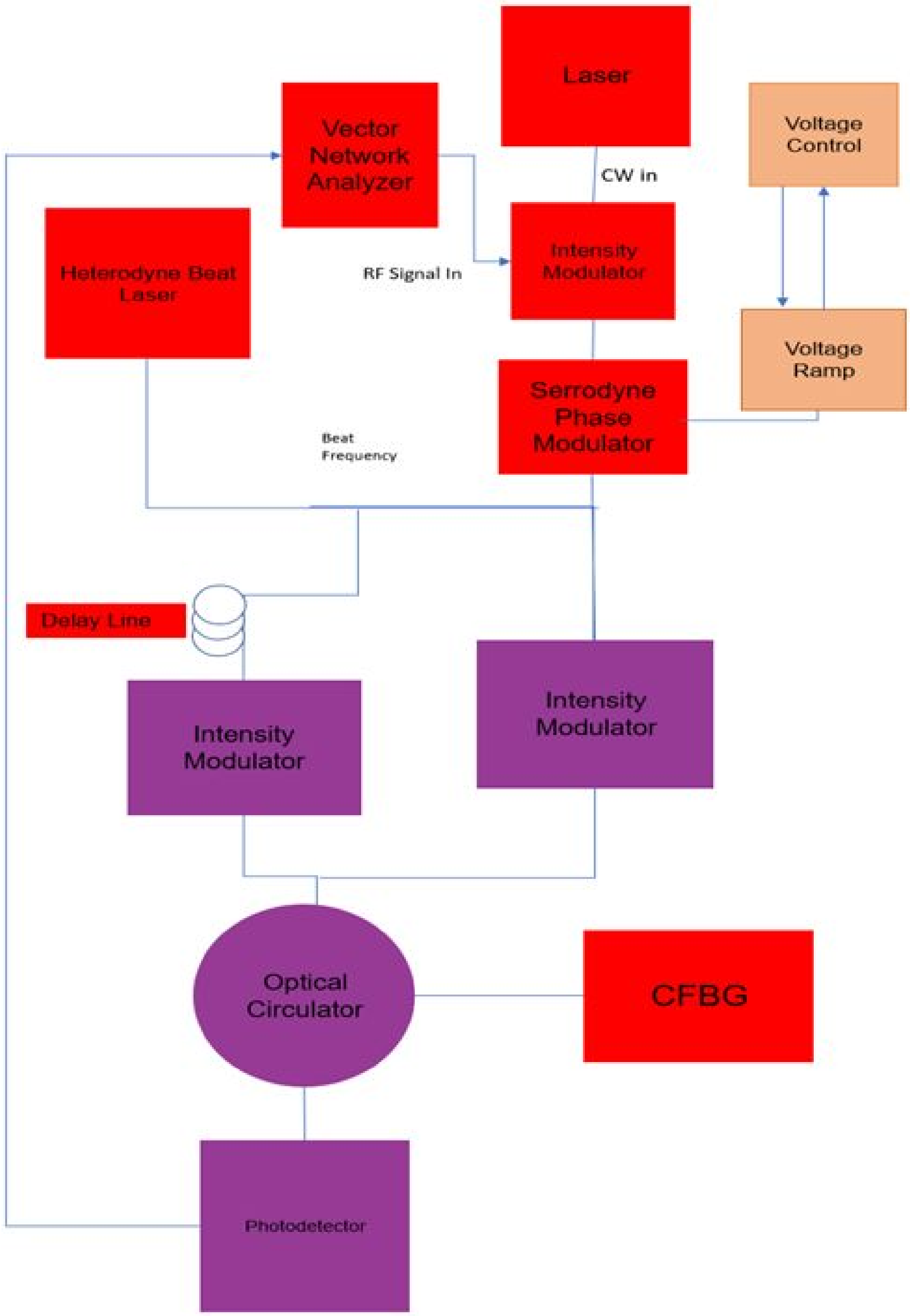

Figure 4: Block Diagram for Serrodyne Approach

Note:
Status of block diagram elements as of 3/8/2018:

- Each block is currently being researched or designed .
- None of the blocks have been purchased or acquired from the sponsor.
- None of the blocks are being prototyped.
- None of the block have been completed.

Milestones

Number	Task	Start	End	Status	Responsible
Spring 2018					
1	**Assign Rolls**	1/16/2018	2/2/2018	Completed	Group
	Project Report				
2	Initial Divide & Conquer	1/16/2018	1/28/2018	Completed	Group
3	Second Divide & Conquer	2/27/2018	3/8/2018	Completed	Group
4	Table of Contents	3/8/2018	3/22/2018	In Progress	Group
5	First Draft	2/9/2018	4/13/2018	In Progress	Group
6	Final Document	3/30/2018	4/26/2018	In Progress	Group
	Research, Document, and Design				
7	Initial Calculations	2/2/2018	2/16/2018	Completed	Group
8	Cavity Options	2/9/2018	3/22/2018	Researching	Group
9	Free-Space Fiber Coupling	3/1/2018	3/23/2018	Researching	C, K, S
10	Serrodyne Approach	3/1/2018	3/23/2018	Researching	K, S
11	Herriott and Corner Cube Approach	2/16/2018	3/23/2018	Researching	C
12	Simulations	3/9/2018	3/30/2018	Researching	C, K, S
13	Motor	2/16/2018	3/23/2018	Researching	M
14	Microcontroller	3/2/2018	4/6/2018	Researching	M
15	Power Supply	3/16/2018	4/6/2018	Researching	K, M
16	Laser	3/9/2018	3/30/2018	Researching	C, K, S
17	Modulator	3/1/2018	4/6/2018	Researching	C, S
18	VNA	3/1/2018	4/6/2018	Researching	C, K, S
19	Signal Detection	3/1/2018	4/6/2018	Researching	C, S
20	Final Design	3/30/2018	4/13/2018	Researching	Group
21	**Order Parts & Prototype Design**	3/30/2018	4/13/2018	Researching	Group
Fall 2018					
22	**Order PCB & Final Parts**	August	October		Group
23	**Build & Test Prototype**	August	October		Group
24	**Finalize Prototype**	September	October		Group
25	**Acquire Necessary Devices from Sponsor**	October	November		Group
26	**Final Build**	October	November		Group
27	**Peer Presentation**	September	TBA		Group
28	**Final Report**	September	TBA		Group
29	**Final Presentation**	September	TBA		Group

MILESTONES KEY:
C = Caleb
K = Kevin
S = Sam
M = Marcus

Budget and Financing

Harris has tentatively given us a budget of around $20-25k, although we plan to keep the funds used on this project well below the budget. We plan on cooperating with Harris to utilize some of their equipment which will reduce the amount of funds required. Harris has been cooperative in this regard.

Some of the equipment provided by Harris will include high speed photodetectors for signal detection, a vector network analyzer for analysis of the delay, and an intensity modulator for modulating on the radio frequency signal. Other equipment that may be provided by Harris includes phase and intensity modulators necessary for serrodyne phase shifting approach and chirped Fiber Bragg Grating. Any equipment not provided by Harris Corporation would need to be purchased with funds from the provided budget.

House of Quality

The House of Quality on the next page summarizes the project's requirements and specification, and how they each relate to one another. The quantitative values associated with the engineering specifications are displayed at the bottom of the House of Quality.

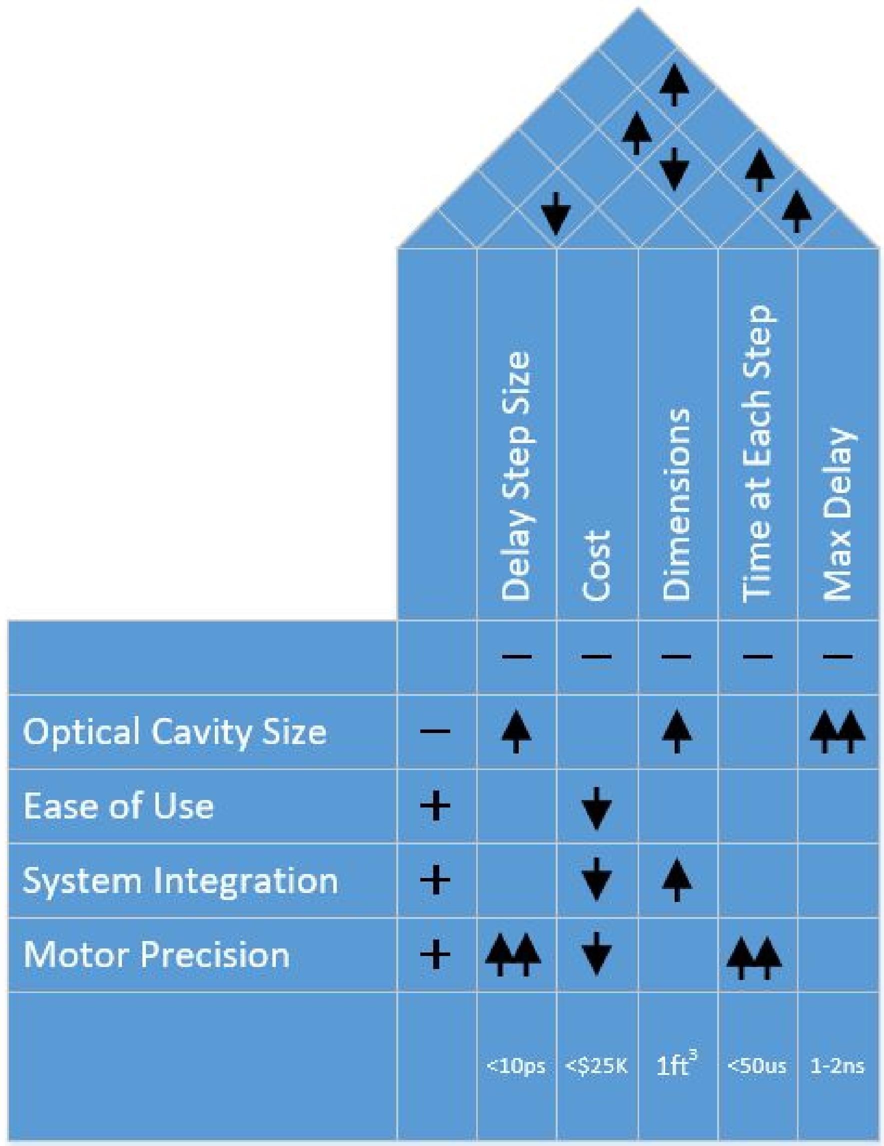

Figure 5: House of Quality

House of Quality Legend

↑= Positive correlation
↑↑= Strong positive correlation
↓= Negative correlation
↓↓= Strong negative correlation
+ = Increases the requirements
- = Decreases the requirement

References

1. C. A. Balanis, Antenna theory analysis and design. Hoboken, NJ: Wiley, 2016.
2. J. Corral, J. Marti, S. Regidor, J. Foster, R. Laming, and M. Cole, “Continuously variable true time-delay optical feeder for phased-array antenna employing chirped fiber grating,” IEEE Transactions on Microwave Theory and Techniques, vol. 45, no. 8, pp. 1531–1536, 1997