Senior Design Project
T307
25 October 2020
Concept Selection

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SECTION I: Concept Selection

1.1: Background

The Concept Selection is a process of analyzing and selecting the best ideas from among the group members. The group members brainstorm several concepts, which are then evaluated based on the probability of a concept moving forward in the design process. Although a practical concept idea would make a good choice, the creativity of the concept should also be taken into consideration when making a decision of an optimal solution. The concept selection will include select types of decision matrices like the Pugh chart, House of Quality, Pairwise Comparison methods, and others.

Note: Some Tables are hard to see in this document, contact information provided at the end of the document if Excel sheets are desired, in addition to final sheet PDFs.

SECTION II: Requirement Analysis

2.1: Background

In the Requirements Analysis phase of the project, the various inputs, outputs, and customer interfaces are defined in greater detail. The functionality of the designed system, or how the system will function is also conceived. Several tools such as the customer tradeoff matrix, which addresses tradeoffs between customer and engineering requirements or between engineering requirements themselves, is an example of the function conceived. This matrix also shows relations between requirements and customer needs.

2.2: Engineering – Customer Tradeoff Matrix

The "Engineering – Customer (Marketing) Tradeoff Matrix" identifies how the requirements of the engineering side impacts the needs of the customer and vice versa. The reasons why some polarity was chosen to be negative is because it may be undesirable to other customers if the product eventually becomes mass produced. For example, the transmission of data of received signal to PC for review is undesirable to a customer already paying a large amount for this product, and eventually should be a self-contained screen within the unit.

Table I: Marketing Matrix

Column1	Engineering Requirements	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure
Customer Need	Polarity	+	+	+	+	+	-	+	+	+	+	-	+	+	+
Prototype of a single unit	+	↑↑		↓				↑	↑						↑
Fast receival of reverse signal	+		↑		↑↑	↑	↑	↑	↑		↑		↑	↑	
Reparability in case of failure	+	↑		↓				↓	↑						↑↑
Show envelope of signal at high frequencies	+		↑↑		↑	↑↑	↑	↑	↑		↑		↑↑	↑↑	
Software code/application needs to be chosen and configured for SDR connection to PC/Display	-						↓↓	↓		↑	↑	↓	↑		↑
Ability to start and stop readings (externally triggered)	+		↑	↑↑		↑		↑	↑	↑	↑				
Cost under $1000	+	↑	↑			↑		↑↑	↑	↑			↑		↑
At least one channel	+	↑	↑		↑	↑		↑	↑↑	↑	↑		↑	↑	
Run for many days/hours	+		↑			↑	↑	↑	↑	↑↑	↑				↑
Range of 600MHz to 800MHz for 1H channel	+		↑		↑	↑	↑	↑	↑		↑↑			↑	
No use of NI products	-						↓	↓				↓↓			

Table 1: Marketing Matrix elements contained in this figure

The “Engineering Tradeoff Matrix” identifies either a positive or a negative correlation by the means of self-comparison or tradeoffs between engineering requirements versus itself.

Table II: Engineering Matrix

Column1	Engineering Requirements	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure
Engineering Requirements	Polarity	+	+	+	+	+	-	+	+	+	+	-	+	+	+
Assembly in a single prototype unit	+														↑
SDR will have enough bandwidth to demonstrate the envelope	+				↑		↑	↑	↑	↑	↑		↑	↑	
Prototype will be connected to an external trigger	+					↑		↑	↑	↑					
Sampling rate of the SDR will be higher than minimum value for correct scan	+						↑	↑	↑		↑			↑	
Will capture the entire sample (pulse train)	+							↑	↑	↑	↑		↑	↑	
Will transmit the digital data of received signal to PC for review, analysis, and storage	-							↑	↑↑	↑	↑		↑	↑	↑
Performs the software and hardware capabilities necessary while staying under budget	+								↑↑	↑↑	↑		↑↑	↑	↑
Must receive experiment output for analysis	+									↑	↑		↑	↑	
Will have external storage of received data	+										↑			↑	
Prototype will record, analyze and plot 600MHz to 800MHz received signals and reflected power	+												↑	↑	
Will not incorporate any National Instruments components nor software	-														
Output digital signal from prototype will have at least 8-bit resolution	+													↑	
Prototype will have several times the bandwidth of the carrier frequency of the pulse	+														
Quick access to hardware or code in software to run diagnostics on the system in case of failure	+														

Table 2: Engineering Matrix elements contained in this figure

SECTION III: House of Quality

3.1: Background

The House of Quality demonstrates the two most important relationships for concept selection: Engineering - Customer Tradeoff Matrix and Engineering Tradeoff Matrix. The former (bottom of the House) shows how Engineering Requirements relate to Customer Requirements. The top of the House shows which of the Engineering requirements have positive or negative or strong positive or negative relationships. The reason for analysis of the bottom is to have a clear vision and understanding of which Engineering Requirements that have been developed have positive or negative relationships. This graphic approach will lead to the choices that have to be made later based on the correlations between the two variables. Similar justification goes to the upper part. The relationship between Engineering Requirements shows which ones are beneficial choices that lead to strengthening the design and positive correlation, and which ones on opposite negatively affect the final performance of the product.

To start the interpretation of the House of Quality (HoQ), all possible relationships must be clearly stated. These interpretations are as follows: positive correlation (up arrow), strong positive correlation (two up arrows), negative correlation (down arrow), and strong negative correlation (two down arrows). To begin analytical discussion and interpretation of the results seen on the fundamental (bottom part) of the HoQ. The following analysis points out most critical parts of this graphical interpretation of the requirements' relationships and will be used in the final concept selection section.

Starting with the customer requirement "prototype of a single unit". This requirement has only one negative relationship with the engineering requirement "prototype will be connected to an external trigger". The reason for this choice is the integration of the trigger within the prototype. The more complex the implementation of the trigger, the harder it will be to keep the prototype as a single unit. Therefore, close attention in the selection of the trigger concept during option selection must be had. In addition to making sure that the trigger implementation will be small enough to not require a separate unit from the main one.

Moving forward from the first customer requirement (CR), the "fast receival of reverse signal" had one strong relationship, namely, with "sampling rate of the SDR will be higher than minimum value for correct scan". Therefore, it is important for final concept selection to choose the SDR with a sampling rate that is at least a double of the minimum required sampling rate. Besides this relationship, there is no place for concern in this when addressing this customer requirement due to the absence of any other negative relationships with the interpreted engineering requirements (ER).

Since the prototype will be used on a daily basis by scientists in the Magnetic Field Laboratory (MAGLAB), there is a direct CR for "repairability in case of failure". Adding to the trigger function implementation concern from the first CR, this CR also has a negative relationship with "prototype will be connected to an external trigger" ER. The reason being is if the trigger is implemented in a complicated, internal manner, the repair in case of failure becomes harder and sometimes not feasible (if the choice of the trigger is not a pin or a FPGA, which can be easily rewired or reprogrammed). Also, this CR relates negatively with the cost ER. The easier it is to repair, the more expensive are the devices used in the prototype. If the choice is made to incorporate devices of lower price, their connection might be not trivial, due to their lack of modularity, therefore the more expensive but easier to repair devices need to be considered for the final concept selection.

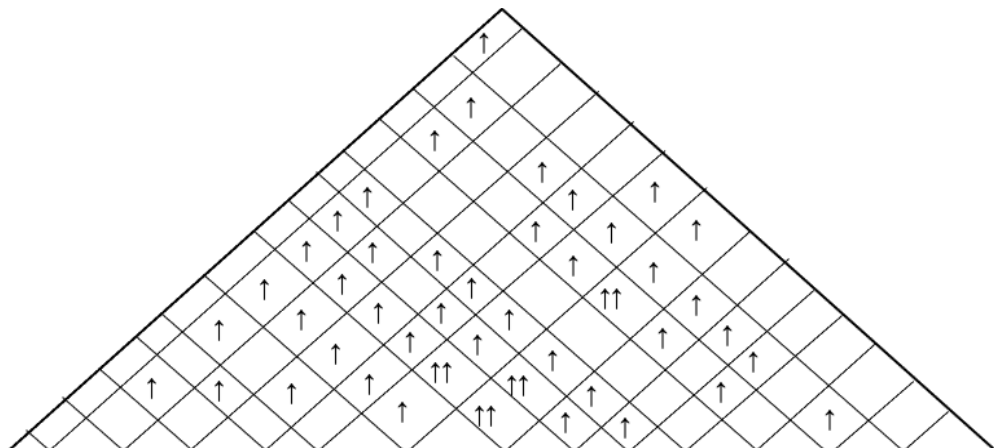
Moving on to the next CR: “show envelope of signal at high frequencies” shows the strong positive relationship with ER: “SDR will have enough bandwidth to demonstrate the envelope”. This relationship tells us that the choice of SDR will be strongly impacted on the bandwidth of its receiver, which limits the selection to SDRs with high bandwidth. This derivation is supported by a strong positive relationship between “show envelope of signal at high frequencies” and “will capture the entire sample”. At the same time the “show envelope of signal at high frequencies” also (third strong positive relation) relates strongly positively with “output digital data from the prototype will have at least 8-bit resolution”. This can be seen as one of the largest constraints, since the lower resolutions of the SDR’s analog-to-digital converter will not show the envelope of the signal at high frequencies with a resolution needed for correct tuning of the probe. As the final strong positive relation for “show envelope of signal at high frequencies” is the “prototype will have several times the bandwidth of the carrier frequency of the pulse” engineering requirement. From the observation that the former customer requirement has four strong positive relationships with the engineering requirements and no negative correlations, it can be deducted that in the selection portion for the design this customer requirement will be fully satisfied.

Continuing the analysis of the CRs brings to light the “software code/application needs to be chosen and configured for SDR connection to PC/Display” requirement. This is the one of the two CRs that has the most negative relationships with the ERs. Based on this it can be observed that the programs used to operate on the output digital data from the SDR must be selected in the manner that will carefully avoid the negative impact on the cost and NI software usage.

The following CRs have only positive relationships with the ERs which aids the designers in the concept selection since there are no negative relationships to consider. They are as follows: “ability to start and stop readings”, “cost under $1000”, “at least one channel”, “run for many days/hours”, and “range of 600 MHz to 800 MHz for 1H channel”. Special attention has to be paid to the reason why the CR “cost under $1000” does not have any negative relationships with any ERs even though in most designs that is not the case. The reason for this anomaly is because SDR devices do not follow linear “the faster - the more expensive” curve. In fact, there are SDRs which cost more and have lower sampling frequencies and lower resolution ADCs. This is due to the fact that those devices with higher cost contain functions that are not particularly necessary for the application (ability to transmit analog signals, include FPGA on the board, etc.). This is why the relationship cannot be described as negative with some of the ERs. However, there are clear positive relations with high bandwidth, software capabilities and external storage since these characteristics are almost always included in any SDR (device concept) and are in the definition of the device's nature. Therefore, it was declared that the cost reduction lower than $1000 actually positively affects some of the engineering requirements that were discussed.

Finally, the second CR that has the most negative relations with ERs is "no use of NI products" requirement. It demonstrates the need to search for concepts that do not include an NI product that has capability to transmit the digital data to the PC and perform all of the software and hardware capabilities while staying under budget. The negative relationships demonstrate that this is the second hardest constraint that must be followed for the satisfaction of customer requirements.

Table III: House of Quality



Customer Requirements / Technical Requirements	Weight	Assembly in a single prototype unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Will transmit the digital data of received signal to PC for review, analysis, and storage	Performs the software and hardware capabilities necessary while staying under budget	Must receive experiment output for analysis	Will have external storage of received data	Record/Analyze/Plot 600MHz to 800MHz	Will not incorporate any National Instruments components nor software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		
Weight		+	+	+	+	+	-	+	+	+	+	-	+	+	+		
Prototype of a single unit	+	↑↑		↓				↑	↑						↑	> 1	1
Fast receival of reverse signal	+		↑		↑↑	↑	↑	↑	↑		↑		↑	↑		>= 11	11ns
Repairability in case of failure	+	↑		↓				↓	↑						↑↑	N/A	N/A
Show envelope of signal at high frequencies	+		↑↑		↑	↑↑		↑	↑		↑		↑↑	↑↑		> 600	800 MHz
Software code/application needs to be chosen and configured for SDR connection to PC/Display	-						↓↓	↓		↑	↑	↓	↑		↑	N/A	N/A
Ability to start and stop readings (externally triggered)	+		↑	↑↑		↑		↑	↑	↑	↑					> 1	2
Cost under $1000	+	↑	↑			↑		↑↑	↑	↑			↑		↑	<= 1k	$1k
At least one channel	+	↑	↑		↑	↑		↑	↑↑	↑	↑		↑			> 1	2
Run for many days/hours	+		↑			↑		↑	↑	↑↑	↑			↑	↑	> 7	14d
Range of 600MHz to 800MHz for 1H channel	+		↑		↑	↑		↑	↑		↑↑					> 600	800 MHz
No use of NI products	-						↓	↓				↓↓		↑		N/A	N/A
Marginal Value		> 1	> 1	> 1	>= 11	>= 11	>= 8	N/A	>= 2.5	> 7	> 600	N/A	>= 8	> 600	N/A		
Ideal Value		1	1Hz	2	11ns	11ns	8bits	N/A	2.5dBm	14days	800MHz	N/A	8bits	800MHz	N/A		

Table 3: House of Quality elements contained in this figure

SECTION IV: Pugh Chart

4.1: Background

The Pugh Chart is a concept selection method that sheds light on which concept is the most promising. It is relatively easy to use, and it compares concepts versus criteria. It is a chart with a matrix base where the rows represent criteria and the columns represent concepts or designs in order to weigh out all the options. In the designs, which include close relationships between several requirements, there is a procedure to be done which includes creating multiple Pugh charts, choosing the best option from the first chart and then using that option in the following chart. This is not the case scenario in the Concept Selection. Since most criteria have a wide spread of relationships among each other and would interconnect poorly. The Pugh chart will be created based on the normalized weights from the pairwise comparison.

Table IV: Pugh Chart

		Option 1	Option 2	Option 3
No National Instruments components or software	7	-	-	-
Output digital signal from prototype will have at least 8-bit resolution	6	-	1	-1
Range of 600-800MHz for received and reflected signals	6	-	1	1
Sampling rate of the SDR will be higher than minimum value for correct scan	5	-	-1	-1
Prototype will have several times the bandwidth of the carrier frequency of the pulse	5	-	-1	-
Will capture the entire sample (pulse train)	5	-	-	-
Quick access to hardware or code in software to run diagnostics on the system in case of failure	4	-	-1	-1
SDR will have enough bandwidth to demonstrate the envelope	3	-	-	-
Prototype will be connected to an external trigger	3	-	1	1
Transmit data signal to PC for review, analysis, and storage	3	-	-	-1
Receive experiment output for analysis	2	-	-	-
External Storage of received data	2	-	-1	-1
Performs the software and hardware capabilities necessary while staying under budget	1	-	-	-
Assembled in a single unit	1	-	-	-
Score		-	-1	-11
Continue?		Yes	No	No

Table 4: Pugh Chart elements contained in this figure

4.2: Chart Outcome

In order to analyze the Pugh outcome, there are some necessary things to consider. If normalized sorted weights are displayed and only three significant figures are considered for comparison (due to similarity of shorter values), then the range of 0.006 is chosen to be considered for equivalent importance. Criteria was made that is present in the second column of the Pugh chart shown in "Table IV". The category weights are distributed as done in the Pairwise Comparison in the next section from 1 (equally important) to 7 (very much more important). Option 1 from Concept Generation was determined to be the reference for the Pugh chart choices of weighted comparison values due to the fact that this option was closest to the ideal implementation of the design. The next two columns of the Pugh chart include Option 2 and Option 3, which were both rated with respect to the reference model. If the choice in the option is better based on the criteria – the positive 1 is assigned. If the choice is worse – the negative 1 is assigned.

The score at the bottom of the chart represents the sum of multiplications between the criteria, and the value assigned by the team to that option's choice. If the result was positive the "Continue?" statement was awarded a "Yes". Oppositely, if the result was negative the output was a "No". Since both Option 2 and Option 3 were awarded a "No" based on the negative scores, the Pugh chart demonstrates that the most optimal choice for the concept selection is Option 1. Option 1 pertained to the Adalm-Pluto SDR, Option 2 pertained to the PlayDUO SDR, and Option 3 pertained to the HackRF One.

SECTION V: Pairwise Comparison

5.1: Background

Pairwise Comparison is a systematic way to compare criteria and requirements to assign weights to the requirements. Each row is compared to each column to determine the importance of one criterion to another. Along the diagonal in the middle is all ones, this is because the criterions are equally matched with themselves. From there, each value's inverse should reflect along this diagonal in relevance to the importance of the comparing criterions.

Once all the above information has been gathered, one can start to see where the importance lies, or which criterions need to have priority in the project. It is easier to see once the geometric mean of each row is calculated. From the geometric mean, the weight of each criterion is then determined. The criterion with the highest value for the weights need to be prioritized more than that of the weights with the lower values.

Table V: Pairwise Comparison

	Performs the software and hardware capabilities necessary while staying under budget	Assembled in a single unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Transmit data signal to PC for review, analysis, and storage	Receive experiment output for analysis	External Storage of received data	Range of 600-800MHz for received and reflected signals	No National Instruments components or software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		Geometric Mean	Normal Weight
Performs the software and hardware capabilities necessary while staying under budget	1	1	1/2	1/2	1/5	1/5	1/2	1	1/2	1/5	1/7	1/5	1/5	1/3		0.37	0.021
Assembled in a single unit	1	1	1/3	1/3	1/5	1/5	1/2	1/2	1/2	1/2	1/7	1/5	1/5	1/3		0.33	0.019
SDR will have enough bandwidth to demonstrate the envelope	2	3	1	1	1/2	1/2	1	2	2	1/3	1/5	1/3	1/2	1/2		0.78	0.044
Prototype will be connected to an external trigger	2	3	1	1	1/2	1/2	1	1	3	1/3	1/5	1/3	1/2	1/3		0.75	0.042
Sampling rate of the SDR will be higher than minimum value for correct scan	5	5	2	2	1	2	2	3	3	1	1/3	1	2	2		1.83	0.103
Will capture the entire sample (pulse train)	5	5	2	2	1/2	1	3	3	3	1	1/2	1	1	2		1.67	0.094
Transmit data signal to PC for review, analysis, and storage	2	2	1	1	1/2	1/3	1	1	2	1/3	1/5	1/3	1/3	1/2		0.68	0.038
Receive experiment output for analysis	1	2	1/2	1	1/3	1/3	1	1	1	1/5	1/7	1/5	1/3	1/3		0.51	0.028
External Storage of received data	2	2	1/2	1/3	1/3	1/3	1/2	1	1	1/5	1/7	1/5	1/5	1/3		0.45	0.025
Range of 600-800MHz for received and reflected signals	5	5	3	3	1	1	3	5	5	1	1/2	1	1	2		2	0.112
No National Instruments components or software	7	7	5	5	3	2	5	7	7	2	1	2	2	3		3.51	0.197
Output digital signal from prototype will have at least 8-bit resolution	5	5	3	3	1	1	3	5	5	1	1/2	1	1	2		2	0.112
Prototype will have several times the bandwidth of the carrier frequency of the pulse	5	5	2	2	1/2	1	3	3	5	1	1/2	1	1	2		1.74	0.097
Quick access to hardware or code in software to run diagnostics on the system in case of failure	3	3	2	3	1/2	1/2	2	3	3	1/2	1/3	1/2	1/2	1		1.18	0.066
Sum	46	49	23.83	25.17	10.07	10.9	26.5	36.5	41	9.3	4.84	9.3	10.77	16.67			

Table 5: Pairwise Comparison elements contained in this figure

Table V.I: Sorted Weights for Pairwise Comparison

Sorted Weights	
No National Instruments components or software	0.197
Output digital signal from prototype will have at least 8-bit resolution	0.112
Range of 600-800MHz for received and reflected signals	0.112
Sampling rate of the SDR will be higher than minimum value for correct scan	0.103
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.097
Will capture the entire sample (pulse train)	0.094
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.066
SDR will have enough bandwidth to demonstrate the envelope	0.044
Prototype will be connected to an external trigger	0.042
Transmit data signal to PC for review, analysis, and storage	0.038
Receive experiment output for analysis	0.028
External Storage of received data	0.025
Performs the software and hardware capabilities necessary while staying under budget	0.021
Assembled in a single unit	0.019

Table 5.1: Sorted Weights elements contained in this figure

Table V.II: Normalized Table for Weights

Normalized Table for Criteria Weight

	Performs the software and hardware capabilities necessary while staying under budget	Assembled in a single unit	SDR will have enough bandwidth to demonstrate the envelope	Prototype will be connected to an external trigger	Sampling rate of the SDR will be higher than minimum value for correct scan	Will capture the entire sample (pulse train)	Transmit data signal to PC for review, analysis, and storage	Receive experiment output for analysis	External Storage of received data	Range of 600-800MHz for received and reflected signals	No National Instruments components or software	Output digital signal from prototype will have at least 8-bit resolution	Prototype will have several times the bandwidth of the carrier frequency of the pulse	Quick access to hardware or code in software to run diagnostics on the system in case of failure		Criteria Weight (W)	Weight Sum Vector W,	Consistency vector
Performs the software and hardware capabilities necessary while staying under budget	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.02	0.03	0.02	0.02	0.02		0.02	0.298	14.324
Assembled in a single unit	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.02	0.02	0.02		0.02	0.269	14.283
SDR will have enough bandwidth to demonstrate the envelope	0.04	0.06	0.04	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.05	0.03		0.04	0.627	14.323
Prototype will be connected to an external trigger	0.04	0.06	0.04	0.04	0.05	0.05	0.04	0.03	0.07	0.04	0.04	0.04	0.05	0.02		0.04	0.613	14.312
Sampling rate of the SDR will be higher than minimum value for correct scan	0.11	0.1	0.08	0.08	0.1	0.18	0.08	0.08	0.07	0.11	0.07	0.11	0.19	0.12		0.11	1.52	14.406
Will capture the entire sample (pulse train)	0.11	0.1	0.08	0.08	0.05	0.09	0.11	0.08	0.07	0.11	0.1	0.11	0.09	0.12		0.09	1.347	14.335
Transmit data signal to PC for review, analysis, and storage	0.04	0.04	0.04	0.04	0.05	0.03	0.04	0.03	0.05	0.04	0.04	0.04	0.03	0.03		0.04	0.548	14.352
Receive experiment output for analysis	0.02	0.04	0.02	0.04	0.03	0.03	0.04	0.03	0.02	0.02	0.03	0.02	0.03	0.02		0.03	0.409	14.33
External Storage of received data	0.04	0.04	0.02	0.01	0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02		0.03	0.37	14.215
Range of 600-800MHz for received and reflected signals	0.11	0.1	0.13	0.12	0.1	0.09	0.11	0.14	0.12	0.11	0.1	0.11	0.09	0.12		0.11	1.595	14.407
No National Instruments components or software	0.15	0.14	0.21	0.2	0.3	0.18	0.19	0.19	0.17	0.22	0.21	0.22	0.19	0.18		0.2	2.822	14.426
Output digital signal from prototype will have at least 8-bit resolution	0.11	0.1	0.13	0.12	0.1	0.09	0.11	0.14	0.12	0.11	0.1	0.11	0.09	0.12		0.11	1.595	14.407
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.11	0.1	0.08	0.08	0.05	0.09	0.11	0.08	0.12	0.11	0.1	0.11	0.09	0.12		0.1	1.399	14.356
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.07	0.06	0.08	0.12	0.05	0.05	0.08	0.08	0.07	0.05	0.07	0.05	0.05	0.06		0.07	0.966	14.41

Table 5.2: Sorted Weights elements contained in this figure

Table V.III: Consistency Check

Avg of Consis Vector, λ	Consistency Index	Consistency Ratio (n = 14, RI = 1.57)
14.349	0.027	0.0171

Table 5.3: Consistency Check elements contained in this figure

SECTION VI: Analytical Hierarchy Process

6.1: Background

The Analytical Hierarchy Process is a systematic process of choosing the best design option based on numbers. It works similarly to a Pugh Chart and Pairwise Comparison combined. The final table shown below works similarly to the Pugh Chart by giving each option a "better-or-worse" score and totaling the score based on the attributed weights to the criteria. The Pairwise Comparison element works to give each option its score. Using the pairwise comparison for each criterion, we compare each design option to give a proper, calculated score.

Use the weights from the Pairwise Comparison for the design options. Next, using the Priority Ratings from the comparisons, shown in the Table VI.XV: "AHP Extensions Combined", the ratings for each option is multiplied by the weight of the criteria. For example, the first column of Table VI.XV is multiplied by the weight of "No National Instruments components or software" to get the corresponding score for each option in that criteria. When all columns are filled out, sum up the scores in the columns to score the designs. Once the designs are scored, the scores are compared to determine the best design options for the project. Here, Design Option 1 featuring the Adalm Pluto SDR is the best design choice based on its score.

However, there are other non-calculated reasons as to why Option 1 is the best choice for this project. The Pluto features a plethora of documentation and previous projects that may prove to be useful for this project regarding collecting data, syncing multiple SDRs, and getting it to function as an oscilloscope for radio frequency (RF) signals. In addition, the Pluto supports more software and languages than the SDRplay Duo and HackRF One, making it more versatile and providing more avenues to traverse in the event one turns out to not be feasible. Because of these extra features, option 1 featuring the Adalm Pluto is the best choice for this project.

Table VI: Analytical Hierarchy Process (AHP)

	W	Option 1	Option 2	Option 3
No National Instruments components or software	0.197	0.066	0.066	0.066
Output digital signal from prototype will have at least 8-bit resolution	0.112	0.044	0.075	0.023
Range of 600-800MHz for received and reflected signals	0.112	0.023	0.044	0.075
Sampling rate of the SDR will be higher than minimum value for correct scan	0.103	0.069	0.023	0.038
Prototype will have several times the bandwidth of the carrier frequency of the pulse	0.097	0.043	0.022	0.043
Will capture the entire sample (pulse train)	0.094	0.031	0.031	0.031
Quick access to hardware or code in software to run diagnostics on the system in case of failure	0.066	0.044	0.026	0.013
SDR will have enough bandwidth to demonstrate the envelope	0.044	0.015	0.015	0.015
Prototype will be connected to an external trigger	0.042	0.009	0.019	0.019
Transmit data signal to PC for review, analysis, and storage	0.038	0.017	0.017	0.009
Receive experiment output for analysis	0.028	0.009	0.009	0.009
External Storage of received data	0.025	0.017	0.01	0.005
Performs the software and hardware capabilities necessary while staying under budget	0.021	0.014	0.008	0.004
Assembled in a single unit	0.019	0.012	0.007	0.004
Score		0.413	0.371	0.354

Table 6: Analytical Hierarchy Process elements contained in this figure

Table VI.I: AHP Extension(s) 1

No National Instruments components or software				
Column1	Option 1	Option 2	Option 3	Prioty
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.1: Analytical Hierarchy Process elements contained in this figure

Table VI.II: AHP Extension(s) 2

Output digital signal from prototype will have at least 8-bit resolution				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1/2	2	0.39
Option 2	2	1	3	0.67
Option 3	1/2	1/3	1	0.2

Table 6.2: Analytical Hierarchy Process elements contained in this figure

Table VI.III: AHP Extension(s) 3

Range of 600-800MHz for received and reflected signals				
Column1	**Option 1**	**Option 2**	**Option 3**	**P**
Option 1	1	1/2	1/3	0.2
Option 2	2	1	1/2	0.39
Option 3	3	2	1	0.67

Table 6.3: Analytical Hierarchy Process elements contained in this figure

Table VI.IV: AHP Extension(s) 4

Sampling rate of the SDR will be higher than minimum value for correct scan				
Column1	**Option 1**	**Option 2**	**Option 3**	**P**
Option 1	1	2	3	0.67
Option 2	1/2	1	1/2	0.22
Option 3	1/3	2	1	0.37

Table 6.4: Analytical Hierarchy Process elements contained in this figure

Table VI.V: AHP Extension(s) 5

Prototype will have several times the bandwidth of the carrier frequency of the				
Column1	**Option 1**	**Option 2**	**Option 3**	**P**
Option 1	1	2	1	0.44
Option 2	1/2	1	1/2	0.22
Option 3	1	2	1	0.44

Table 6.5: Analytical Hierarchy Process elements contained in this figure

Table VI.VI: AHP Extension(s) 6

Will capture the entire sample (pulse train)				
Column1	**Option 1**	**Option 2**	**Option 3**	**P**
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.6: Analytical Hierarchy Process elements contained in this figure

Table VI.VII: AHP Extension(s) 7

Quick access to hardware or code in software to run diagnostics on the system				
Column1	**Option 1**	**Option 2**	**Option 3**	**P**
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.7: Analytical Hierarchy Process elements contained in this figure

Table VI.VIII: AHP Extension(s) 8

SDR will have enough bandwidth to demonstrate the envelope				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.8: Analytical Hierarchy Process elements contained in this figure

Table VI.IX: AHP Extension(s) 9

Prototype will be connected to an external trigger				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1/2	1/2	0.22
Option 2	2	1	1	0.44
Option 3	2	1	1	0.44

Table 6.9: Analytical Hierarchy Process elements contained in this figure

Table VI.X: AHP Extension(s) 10

Transmit data signal to PC for review, analysis, and storage				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	2	0.44
Option 2	1	1	2	0.44
Option 3	1/2	1/2	1	0.22

Table 6.10: Analytical Hierarchy Process elements contained in this figure

Table VI.XI: AHP Extension(s) 11

Receive experiment output for analysis				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	1	1	0.33
Option 2	1	1	1	0.33
Option 3	1	1	1	0.33

Table 6.11: Analytical Hierarchy Process elements contained in this figure

Table VI.XII: AHP Extension(s) 12

External Storage of received data				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.12: Analytical Hierarchy Process elements contained in this figure

Table VI.XIII: AHP Extension(s) 13

Performs the software and hardware capabilities necessary while staying				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.13: Analytical Hierarchy Process elements contained in this figure

Table VI.XIV: AHP Extension(s) 14

Assembled in a single unit				
Column1	Option 1	Option 2	Option 3	P
Option 1	1	2	3	0.67
Option 2	1/2	1	2	0.39
Option 3	1/3	1/2	1	0.2

Table 6.14: Analytical Hierarchy Process elements contained in this figure

Table VI.XV: AHP Extensions Combined

Column1	P1	P2	P3
1	0.33	0.33	0.33
2	0.39	0.67	0.2
3	0.2	0.39	0.67
4	0.67	0.22	0.37
5	0.44	0.22	0.44
6	0.33	0.33	0.33
7	0.67	0.39	0.2
8	0.33	0.33	0.33
9	0.22	0.44	0.44
10	0.44	0.44	0.22
11	0.33	0.33	0.33
12	0.67	0.39	0.2
13	0.67	0.39	0.2
14	0.67	0.39	0.2

Table 6.15: Analytical Hierarchy Process elements contained in this figure

SECTION VII: Final Concept Selection

7.1: Background

The final concepts were selected via the following figure:

Figure I: Concept Selection Flowchart

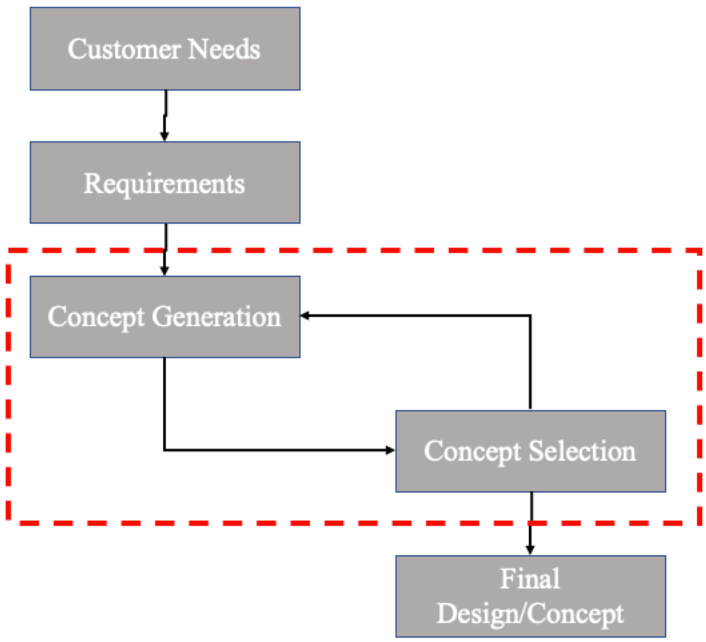


Figure 1: Concept Selection Flowchart elements contained in this figure

This figure provides a flowchart which allows for the team to consider all the possible choices generated at the time of Concept Generation, and then consider one by one before landing on a final selection. This often in return means referencing the tables that were globally obtained in the Concept Selection stage and approving such choice or going back to weigh the outcome of a different Concept from the Generation. Using this flowchart, the components of the final prototype can be well determined, in effect creating a quantitative and satisfactory product.

7.2: Summary

The outcome of the tables (charts) were discussed in their prospective backgrounds or after the table was posted whilst still in that section. That concludes the preparation steps necessary to take in order to evaluate side-by-side correlations within each "molecule" or component in the project. The dissection of concepts and criteria poses a nice benefit, which is to add to the high-fidelity concepts explored in the concept selection phase by evaluating each, as discussed in “Section 7.2” in return making the final concepts a level above high (i.e. extra credit after an assignment already has achieved an A).

The final concept was generated via critical team thinking, weighing out the many outcomes that can be seen in the tables, and following the flowchart discussed previously. Through the Marketing and Engineering Matrices, the HoQ, Pugh Chart, Pairwise Comparison, and lastly the Analytical Hierarchy Process the final concept can be calculated.

From looking at the Concept Generation high fidelity options and the methodologies introduced above the team can then select precise components for the project. From the HoQ, derived from the Marketing and Engineering Matrices (which was extensively discussed in “Section 3”) direct positive and negative correlations can be obtained for the final concept selection since it is known what the expected performance will be.

From the HoQ, it was finalized that only one SDR will be necessary, one that contains two channels and defeats the other options as observed in the Pugh chart. This SDR was chosen to be the Adalm-Pluto SDR, the concept selection was also taking into account the sampling rate that is at least double a minimum required sampling rate. The trigger implementation, keeping in mind the things discussed from the HoQ, was carefully thought of to be externally triggered via a separate Printed Circuit Board (PCB) that will be included in the prototype box and likely to be directly soldered onto the SDR itself. In addition to this, the software chosen will be MATLAB in order to have a backup plan as a software trigger in lieu of potential failure. The negative result due to this choice may be a harder repairability function in case of failure, but when weighed out against the satisfaction of achieving the customer need it is crucial to make these tough decisions. Other decisions that were made after determining the sacrifice of easy repairability (by looking at correlations and the medium high hierarchy weight) in order to keep that desirable cost low was choosing devices of lower price. To further expand on this idea, a budget of two-thousand dollars was allocated to this project but nearly a little over a fourth of the budget was used to order parts. Additional things satisfied via these selections include “ability to start and stop readings”, “cost under $1000”, “at least one channel”, “run for many days/hours”, and “range of 600 MHz to 800 MHz for 1H channel”. The extra functionalities of other choices would provide things that are outside the scope of this project (i.e. higher cost, higher channel count or resolution).

In the Pugh Chart section, the outcome was extensively discussed. The choice in the previous paragraph from this outcome was “Option 1” the Adalm-Pluto SDR. As a means to keep the summary short, there are no other things to discuss that the Pugh chart helped choose for the final selection besides enforcing that the team made the correct choice. As an additional thing to mention however, from the concept selection knowing that the Adalm-Pluto will be the SDR of choice, the team can cut down all connections to PC via USB, since that is the one that works with that SDR selection. The selection of the SDR was the most important aspect of the concept selection, as most other concepts concatenate to this tremendous decision. For this exact reason, other decisions can be finalized. Some include: the attenuators needed to abide by the RF thresholds from the Pluto, a connection to power is used through USB connection via about

500mA, choice of internal SDR and if necessary a MATLAB function implementing a circular buffer, and a keyboard interface to work with the computer attached to the SDR. The selection of prototype box shape conceptually will be obtained during the prototyping phase, since this is dependent on the other selections previously mentioned. It is important to note that the assembly in a single unit has the lowest weight (obtained from this next section).

From the Pairwise Comparison, the weights provide the teams choices verifiable. In other words, these weights can be sorted after the chart has been normalized in order to view the grade-scale quantitatively of each engineering requirement. As a result of the pairwise comparison, the decision to satisfy the Sponsor and abide by avoiding National Instrument components was achieved.

Finally, from the Analytical Hierarchy Process (AHP), it can be observed that the Pairwise Comparison step is crucial. The normalization of the Pairwise Comparison table, obtained from the HoQ and Pugh Table observations, and its consistency check derive the weights for the AHP. Within its section itself, the AHP is extensively discussed. It can be observed that the hierarchy obtained positively reinforced all the choices thus far.

Given the entirety of this document, the variables considered, data acquired, criteria generated, and careful selection and analysis; the team stands in a comfortable place to say the official concept selection can come to a conclusion. The aforementioned points brought to attention should not be taken lightly as they “drive the gears” to mobilize this project and allow for the prototyping or design phase to begin.

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