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Abstract

The Taguchi Method is a statistical approach for achieving robustness in product and process design, with widespread relevance across engineering, manufacturing, and quality assurance. This report investigates the application of the Taguchi Method to a mechanical system, a catapult, to analyse its performance and optimise control settings for maximum range and minimal sensitivity to noise. An experimental framework is established using an L8 orthogonal array to evaluate seven control factors across two levels, reducing the number of required tests while preserving analytical integrity.

The methodology includes systematic trials across two firing sets, guided by a defined experimental matrix and strict control of noise factors. Key variables such as Band Force Potential (BFP) and Pull-Back Angle (PBA) are identified through statistical analysis and signal-to-noise ratio evaluations, with subsequent testing focused on these primary influencers. Midpoint values of the critical factors are predicted to yield an optimal range of 184.95 cm.

Processed data is graphically and statistically analysed to derive insights into the relationship between control settings and output variability, highlighting the effects of human factors, interaction terms, and the benefits of robust experimental design. While Firing Set 3 was not conducted due to coordination challenges, predictions made from the initial runs support the effectiveness of the chosen settings.

This study demonstrates the utility of the Taguchi Method in understanding complex system behaviours, enabling predictive modelling and performance enhancement. It further emphasises the importance of structured experimentation and team coordination in achieving reliable engineering outcomes, offering practical recommendations for future experimental validation and process refinement.

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List of Abbreviations

S/N	Signal Noise Ratio
SP	Stop Position
PBA	Pull Back Angle
OA	Orthogonal Array
HF	Human Factors
BFP	Band Front Position
BAP	Band Anchor Position

1 Objective of Taguchi Exercise

When achieving robustness in process designs the product is of significance to various stakeholders such as manufacturers, and those they supply to. Genichi Taguchi, the originator of the famed Taguchi Methods, also commonly referred to as the approach to a Robust Design. This is due to his profound influence on product development, engineering and the global quality movement [1].

Variability is present in all operations, using taguchi methods he was able to design an experiment that is predominantly data driven. Enabling the identification, testing, and evaluation of key control factors, for things such as but not limited to, settings or processes affecting the operation and performance for a given system or product. From this desirable products can be derived that are insensitive to factors that cannot be controlled.

In this Taguchi methods exercise, a catapult was evaluated using provided equipment, an experimental matrix, and safe firing protocols. Controlled tests gathered performance data, which was analysed to assess control factor influence and develop a predictive model for catapult behaviour. This approach supports deeper understanding of system dynamics and operational optimisation.

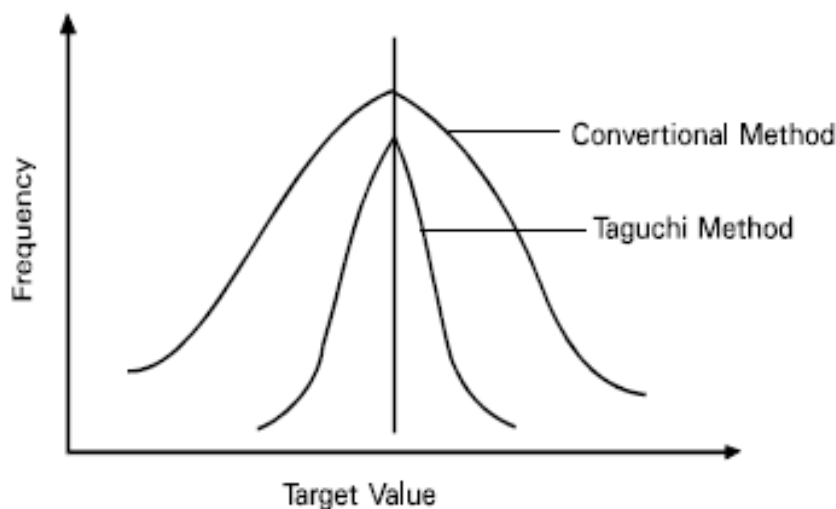


Figure 1 Comparison of Conventional and Taguchi Methods [2]

Typically, the taguchi method adopts an optimised two-step procedure to achieve robust product and process design [2]. Initially, the signal-to-noise (S/N) ratio is

maximised, whilst adjustment to the factors is applied. Orthogonal arrays serve as the experimental backbone, determining factor settings for obtaining data for analysis. Using this method results in far fewer runs than full factorial designs [3].

In the catapult experiment firing set one will provide data on the distance measured due to the change of independent variables, this data will identify the catapults key features. Firing set two will create refined data sets using this key feature data, providing insight based on averages of data from the first firing. Finally the third firing would have validated the predictions previously stated.

2 Apparatus and Method

2.1 Apparatus

- G Clamp
- Catapult
- Tape Measure
- Table
- Weighted Ball
- Elastic Band



Figure 2 Catapult System Setup

2.2 Method

2.2.1 Method: Setup for Taguchi Experiment

1. Equipment Preparation

- A stable table surface was selected to conduct the experiment.
- A G-clamp secured the catapult to the table, minimising movement and kickback to reduce noise factors (see Figure 2).

Noise Factors are anything that causes a functional characteristic or response to deviate from its target value, such variance is unwanted, to minimise the effects of these, control factors were introduced [4].

2. Initial Catapult Setup

- The catapult was inspected to confirm correct assembly and operational readiness.
- An elastic band provided the launch force and was consistently positioned for each trial.

3. Measurement Setup

- A tape measure, aligned with the launch point, recorded the ball's travel distance.
- The zero point of the tape measure was aligned precisely with the catapult's launch position.
- A ruler was kept nearby for fine measurements.

4. Projectile Preparation

- A weighted ball was used as the projectile for all test firings to maintain consistency across trials.

5. Experimental Matrix Execution

- The Taguchi experimental matrix provided was used to determine the specific control settings (e.g., pull-back distance, launch angle, band tension) for each trial of the five trials.
- Each trial was conducted according to the matrix, adjusting the relevant control factors as specified.
- For each firing, the distance travelled by the ball was recorded using the tape measure, following safe firing protocols to ensure consistent, repeatable measurements.

6. Data Recording

- All experimental conditions and results were documented carefully to enable later analysis of key control factors influencing the catapult's performance.

3 Interpretation of Experimental Data

3.1 Orthogonal Arrays

Employing Taguchi's tabulated designs ensures unbiased and efficient data collection across multiple factors and levels. When the number of factors or levels exceeds an array's capacity, a higher-order orthogonal array is selected to preserve true orthogonality and avoid repeated patterns.

Orthogonal Arrays (OA)	Number of factors	Levels of factors	Number of experiment for OA	Number of experiment for full factorial design
L4 (2^3)	3	2	4	8
L8 (2^7)	7	2	8	128
L9 (3^4)	4	3	9	81
L12 (2^{11})	11	2	12	2048
L16 (2^{15})	15	2	16	32768
L16 (4^3)	5	4	16	1024
L18 ($2^1 \times 3^7$)	1	2	18	4374
	7	3		

Figure 3 Orthogonal Array Configurations [5].

Table 2 lists the factors and their corresponding levels for this experiment. Although the chosen orthogonal array can accommodate up to seven factors, our catapult study focuses on four primary variables:

- Band Force Potential (BFP)
- Band Anchor Position (BAP)
- Stop Position (SP)
- Pull-Back Angle (PBA)

To capture critical interactions, BFP $\times$ BAP and SP $\times$ PBA terms. Were added, An additional "operator" factor is also varied to account for handling-related variability.

Table 1 Noise and Control Factors of Experiment

Noise	Control
Kick back when firing catapult	G -Clamp was introduced
Ball aerodynamics	Location of experiment preformed in room with minimal airflow.
Wear of rubber band, elastic degradation	Periodic replacement
Measurement variation	Same human each run
Placement in cup	Un-able to control
Design tolerances of equipment	Un-able to control
Human factors firing sequence	Un-able to control

Table 2 Controls and Variable Factors

Independent Variables							
	Band front position	Band Anchor position	1,2 Interaction	Stop Position	Pull back	2,4 Interaction	Operator
Independent Variables (What is Controlled)							
	Band front position	Band Anchor position	1,2 Interaction	Stop Position	Pull back	2,4 Interaction	Operator
Levels (How it is Controlled)							
level 1	1	2	NA	1	140	NA	A
level 2	3	4	NA	3	170	NA	B
Dependent Variables							
	Range			Horizontal			

For seven factors at two levels each, Table 2 Array, captured in eight runs the insights that a full $2^7=128$ experiment design would require

Table 3 Level 8 Orthogonal Array Matrix

Orthogonal Array							
Factor	1	2	3	4	5	6	7
	A	B	AB	C	D	BC	E
Expt 1	1	1	1	1	1	1	1
Expt 2	1	1	1	2	2	2	2
Expt 3	1	2	2	1	1	2	2
Expt 4	1	2	2	2	2	1	1
Expt 5	2	1	2	1	2	1	2
Expt 6	2	1	2	2	1	2	1
Expt 7	2	2	1	1	2	2	1
Expt 8	2	2	1	2	1	1	2

Table 3 merges Table 2's lay out with the variables and levels defined in Table 1, providing the operator with the exact factor-level settings required for each firing.

Table 4 Populated Level 8 Orthogonal Array Matrix

Experiment	Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator	Variable. Range
1	1	2	1	1	140	1	A	113.6
2	1	2	1	3	170	2	B	296.4
3	1	4	2	1	140	2	B	110.4
4	1	4	2	3	170	1	A	168
5	3	2	2	1	170	1	B	137.4
6	3	2	2	3	140	2	A	48.8
7	3	4	1	1	170	2	A	97.4
8	3	4	1	3	140	1	B	88.4

3.2 . Experimental Run One

Table 5 Run One Data

Experiment Number	Shot Number					Average
	1	2	3	4	5	
1	122	106	106	118	116	113.6
2	305	295	290	298	294	296.4
3	115	109	110	109	109	110.4
4	189	154	146	179	172	168
5	148	139	137	133	130	137.4
6	76	30	30	76	30	48.8
7	92	91	102	110	92	97.4
8	88	89	89	89	87	88.4

Each experiments average range was calculated using the mean formula (Equation 1). The same formula was also applied, determining each factor at both levels. This can be seen in Table 5 Analysis found that BFP Level 1 provided an average of 172.1cm. While these averages highlight performance differences, Taguchi's core focus is robustness: Equation 2 applies the "larger-is-better" S/N ratio to quantify each level's resistance to noise-induced variation, with higher values indicating greater robustness.

Graphs illustrating the variation in range and S/N ratios across factor levels offer visual insight into the data. Appendix A contains the complete set of Independent Variable Level and Range graphs, while Appendix B presents the full collection of S/N against Level graphs.

Equation 1 Band Front Position Level One Average [2]

$$\mu = \frac{1}{n} \sum_{i=1}^n x_i$$

$$\mu = \frac{1}{4}(113.6 + 296.4 + 110.4 + 168)$$

$$\mu = 172.1 \text{ cm}$$

Equation 2 S/N Ratio Level One Band Front Position [2]

$$SNRatio = -10 \log_{10} \left(\frac{\sum_{i=1}^n \frac{1}{y_i^2}}{n} \right)$$

$$SNRatio = -10 \log_{10} \left(\frac{\left(\frac{1}{113.6^2} + \frac{1}{296.4^2} + \frac{1}{110.4^2} + \frac{1}{168^2} \right)}{4} \right)$$

$$SNRatio = 42.87 \text{ cm}$$

Table 6 Run One Processed Data

	Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator
Level 1	688.4	596.2	595.8	458.8	361.2	507.4	427.8
Level 2	372	464.2	464.6	601.6	699.2	553	553
L1 Average (cm)	172.1	149.05	148.95	114.7	90.3	126.85	106.95
L2 Average (cm)	93	116.05	116.15	150.4	174.8	138.25	138.25
Level Difference	79.1	33	32.8	-35.7	-84.5	-11.4	-31.3
S/N L1	42.87	38.53	40.94	41.00	37.52	41.34	37.97
S/N L2	37.53	40.57	38.31	38.28	42.90	38.11	41.64
S/N Difference	5.34	-2.04	2.63	2.72	-5.38	3.23	-3.67

Graphs of range and S/N ratio verses factor levels (see Appendices A and B) allow visual comparison of each variable's effect. From this analysis, the most robust settings are Level 1 for BFP, BAP, SP, and Operator, and Level 2 for PBA. Operator and interaction effects showed minimal variation, although the AB interaction rose slightly with level. The greatest variability appeared in PBA and BFP for both metrics, identifying them as primary factors for Firing Set 2. Overall,

S/N and average-range trends agreed except for the operator choice: Operator B delivered a higher mean range, also superior robustness per its S/N ratio.

3.3 Experimental Run Two

Table 7 Run Two Data

	KF1	KF2		1	2	3	4	5	Ave
Firing 1	1	140	range	138	138	138	140	140	138.8
Firng 2	3	140	range	110	105	106	106	105	106.4
Firing 3	1	170	range	283	283	293	290	284	286.6
Firng 4	3	170	range	208	208	207	207	210	208

In Firing Set 2, the processed data table presents the mean ranges for each level of BFP and PBA, then calculates the combined midpoint range across these two key factors. All other non-critical factors maintained constant levels and were not separately recorded during this phase.

Table 8 Run Two Processed Data

Key Features	Level	Average Range (cm)	Midpoint Range (cm)	Combined Range (cm)	OP.
Band Front Position	1	212.7	184.95	184.95	B
	2	157.2			
Pull Back Angle	1	122.6	184.95		
	2	247.3			

To consistently target this range we must identify the key features midpoint. Table 9 identified at position two BFP, and 155° PBA .184.95 cm, average range can be reached.

4 Conclusion

The Taguchi Method is a structured statistical technique used to enhance design robustness by minimising the impact of noise factors. In this investigation, the method was applied to a catapult system. Objectives were addressed across two firing sets, during which both control and noise factors were identified to help mitigate variability.

An L8 orthogonal array (OA) was selected to accommodate the seven factors under consideration, each at two levels. Experimental data was gathered based on the OA's prescribed settings and analysed to determine which factors had the greatest influence on performance. The Band Force Potential (BFP) and Pull-Back Angle (PBA) emerged as key variables.

From this, specific settings, BFP Positions 1 and 3, and PBA angles of 140° and 170° were selected for further testing in Firing Set 2. The midpoint settings, BFP Position 2 and PBA at 155°, were predicted to yield an average range of 184.95 cm. Although Firing Set 3 was not conducted in this investigation, it is expected that applying the midpoint settings would yield an average range resulting in a predicted margin of error to conclude the results.

5 Reflection

Throughout this project, team dynamics presented significant challenges that impacted the overall outcome of the experiment. The group began the task without everyone's input this failed to establish effective communication channels, which led to a fragmented understanding of the experimental objectives and procedures. As a result, key elements of the investigation, such as conducting a third firing set to confirm the predicted average range and calculate the margin of error, were not completed.

Despite these setbacks, the experiment still offered valuable insights. One notable observation was the variability introduced by changing operators, highlighting the influence of human factors on experimental outcomes. This reinforced the importance of consistency in data collection and demonstrated how operator differences can introduce unexpected variation. Moving forward, greater emphasis will be placed on ensuring clear team coordination and defining responsibilities early on to avoid similar issues and strengthen the reliability of results.

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Appendices

Appendix A

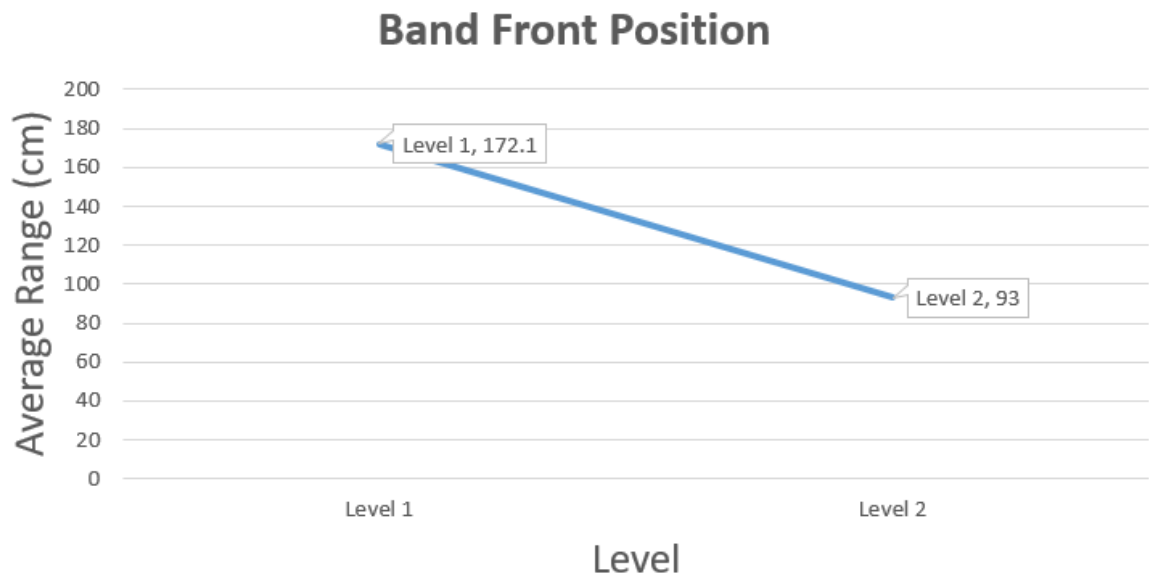


Figure 4 Band Front Position Graph

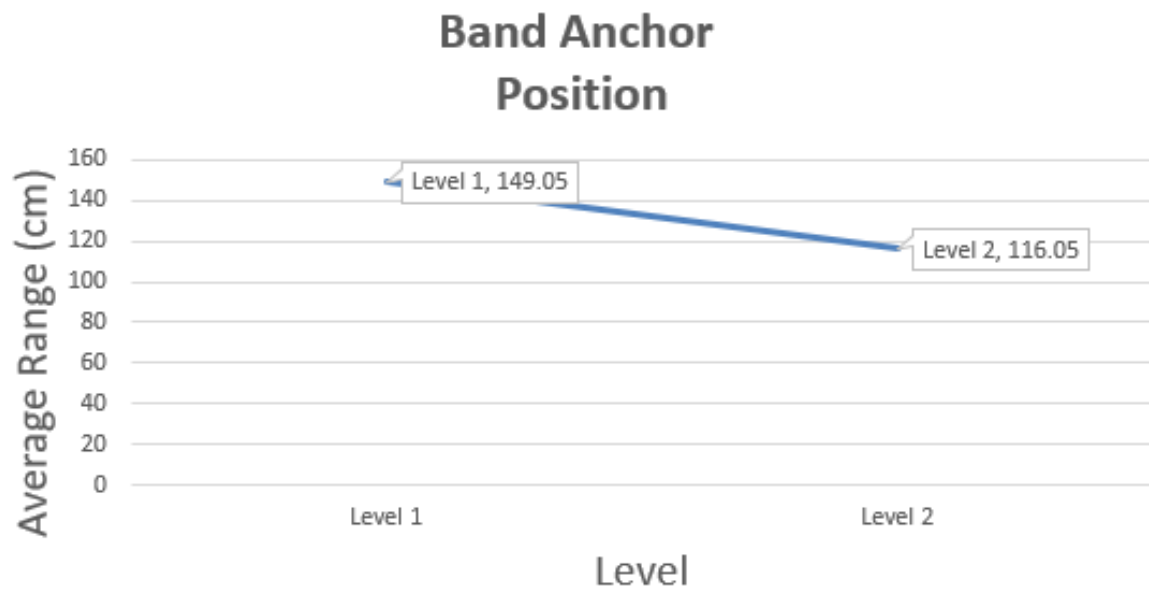


Figure 5 Band Front Position Graph

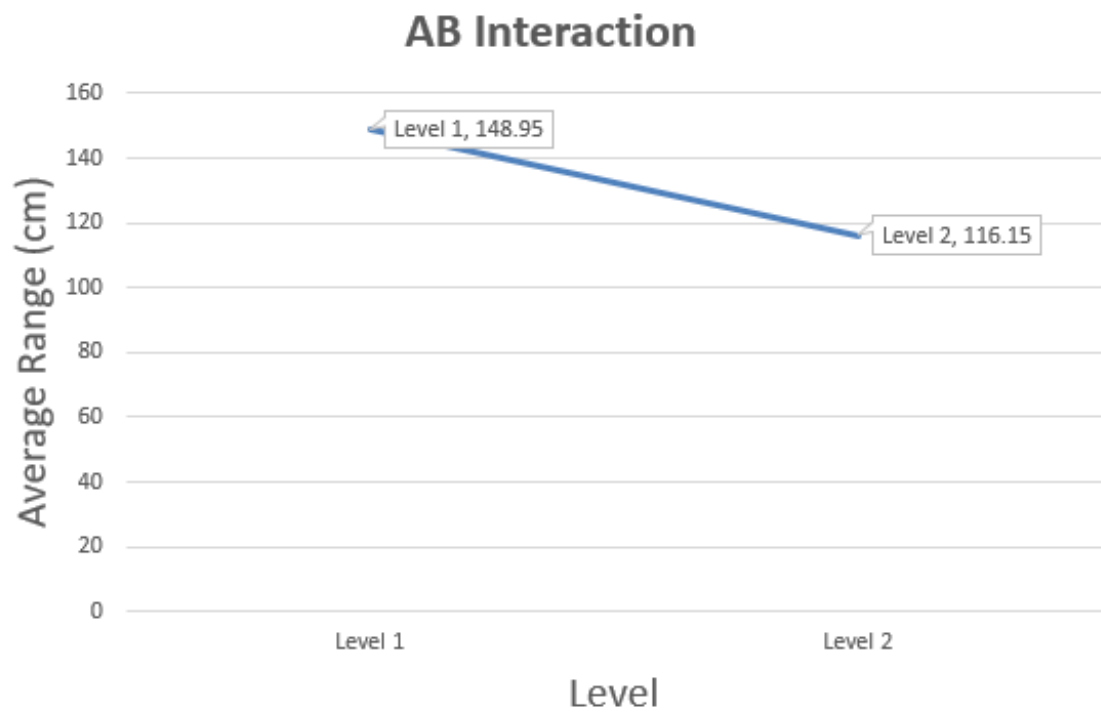


Figure 6 AB Interaction Graph



Figure 7 Stop Position Graph

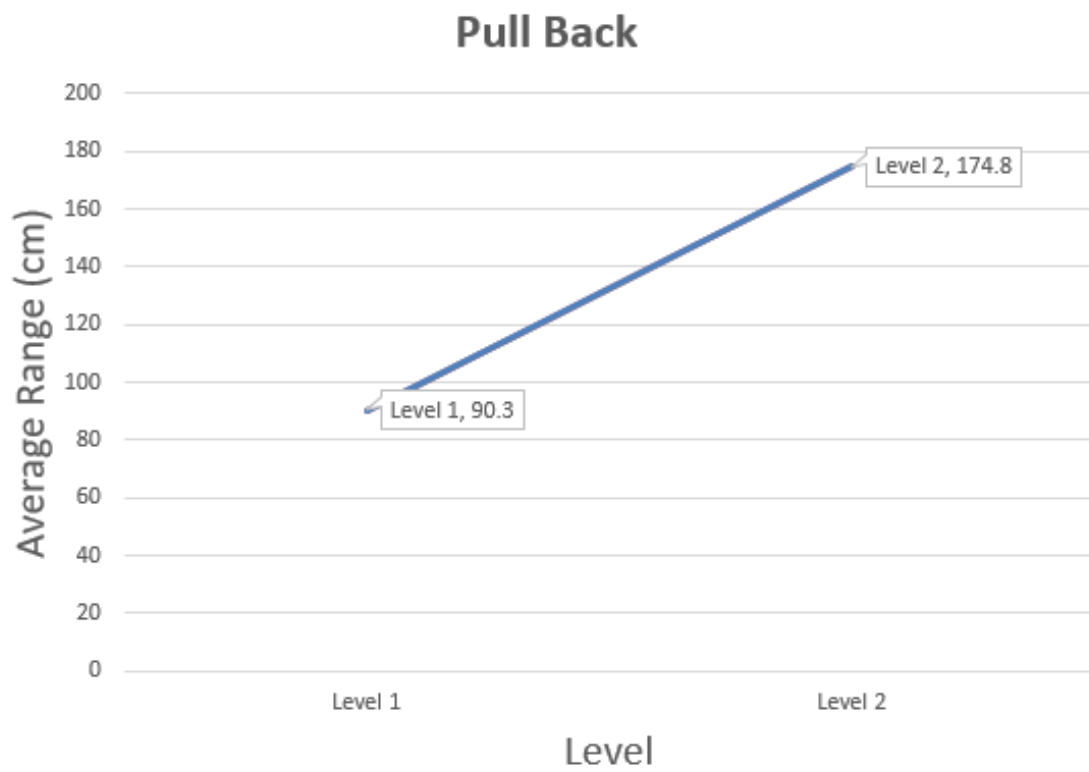


Figure 8 Pull Back Graph

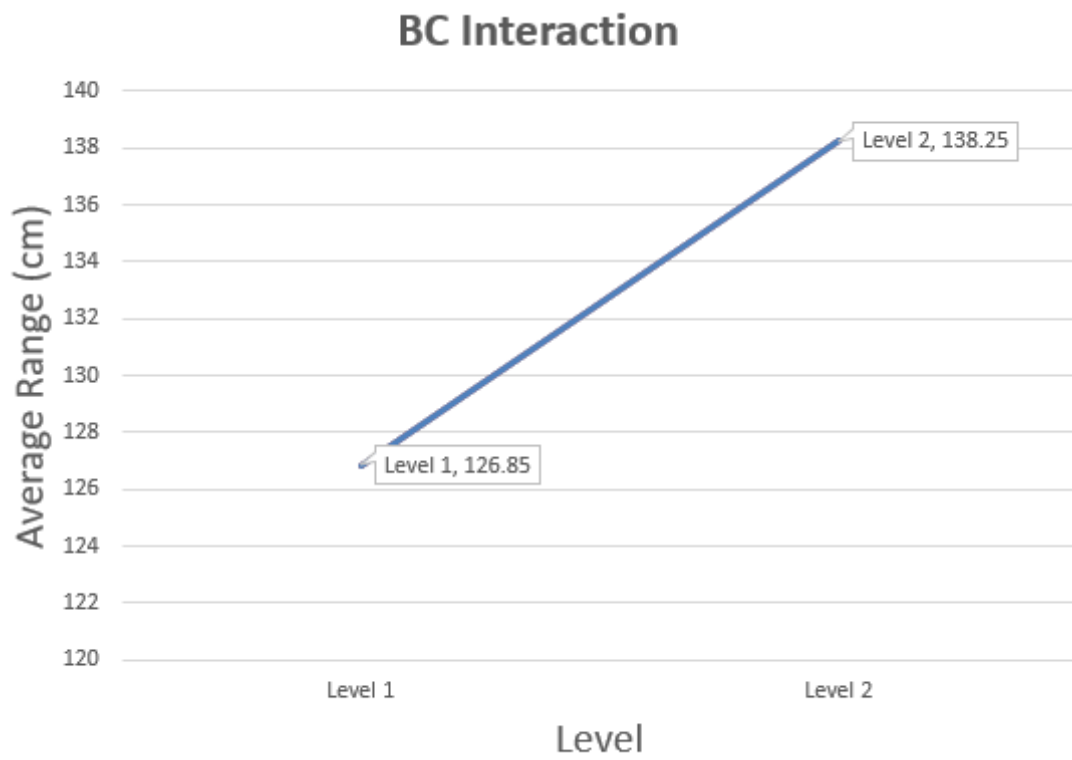


Figure 9 BC Interaction Graph

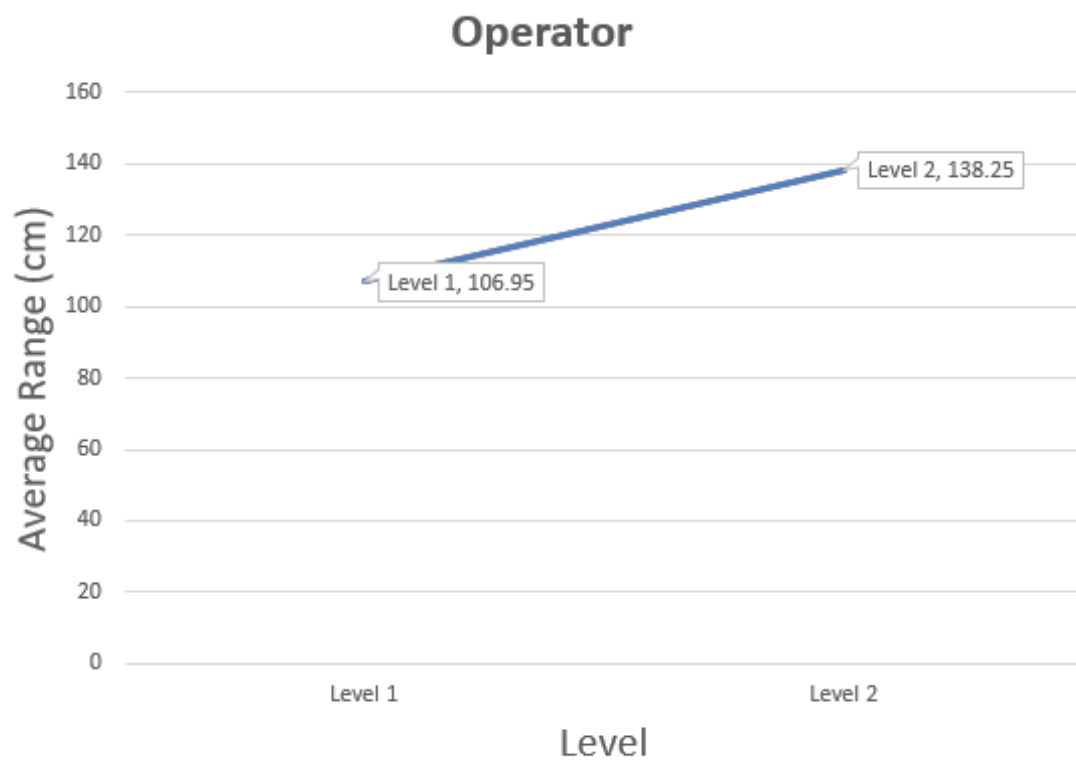


Figure 10 Operator Graph

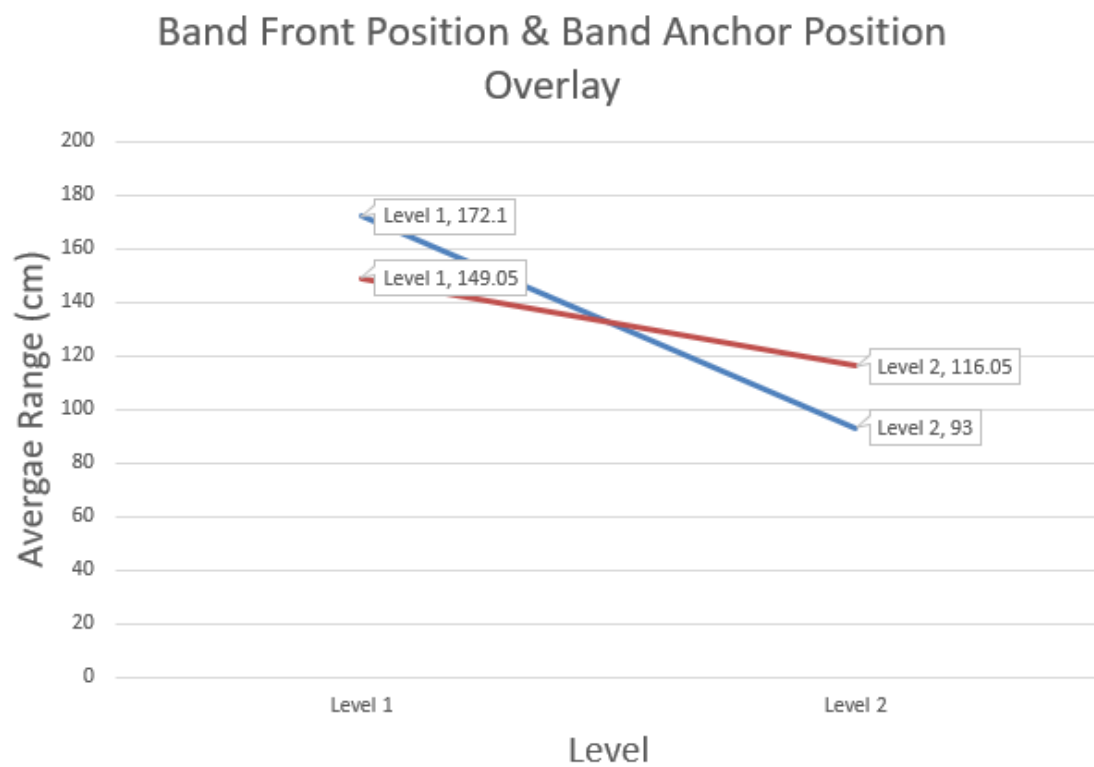


Figure 11 Band Front Position & Band Anchor Position Graph

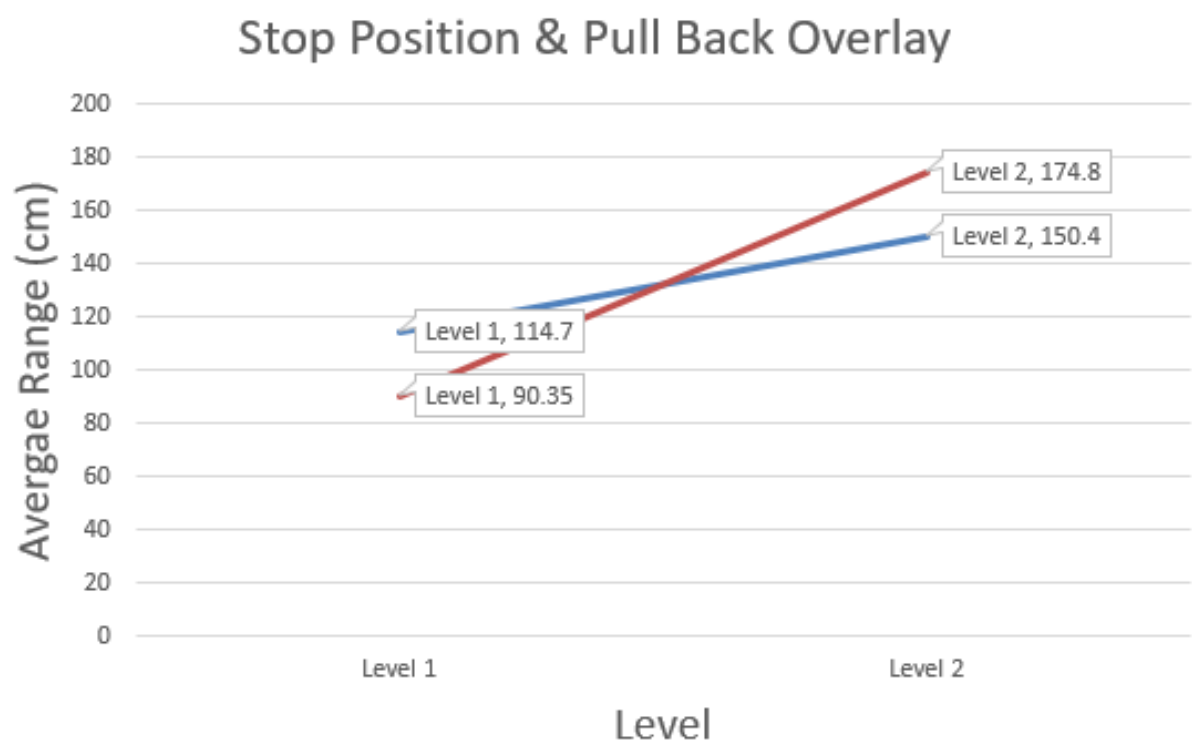


Figure 12 Stop Position & Pull Back Overlay Graph

Appendix B

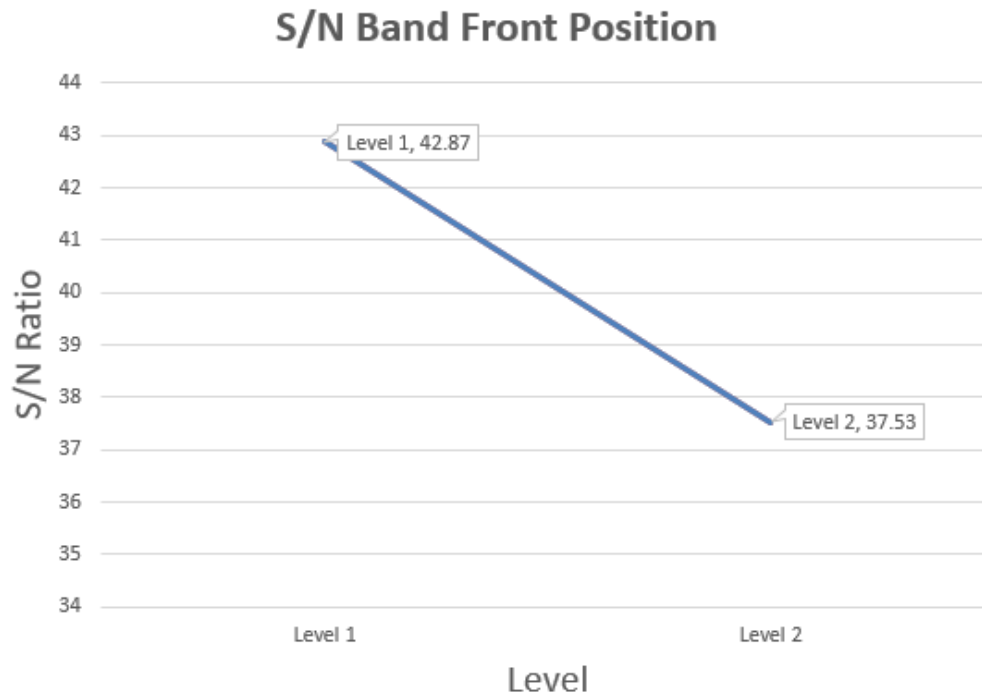


Figure 13 S/N Band Front Position Graph

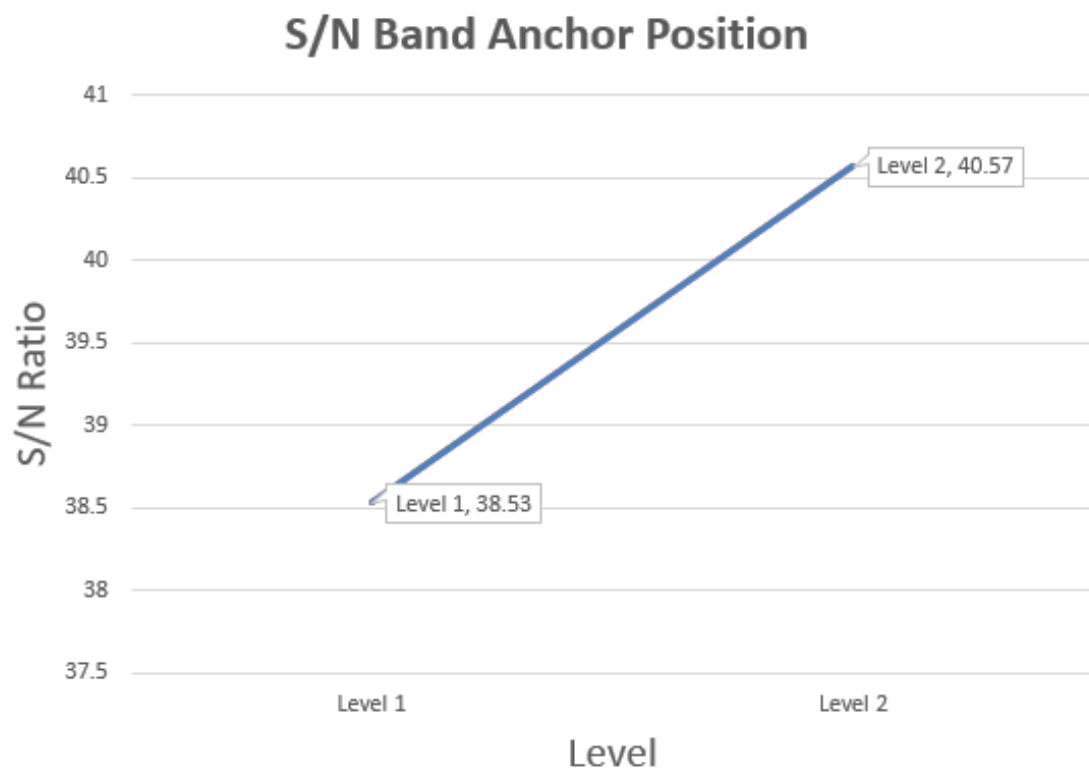


Figure 14 S/N Band Anchor Position Graph

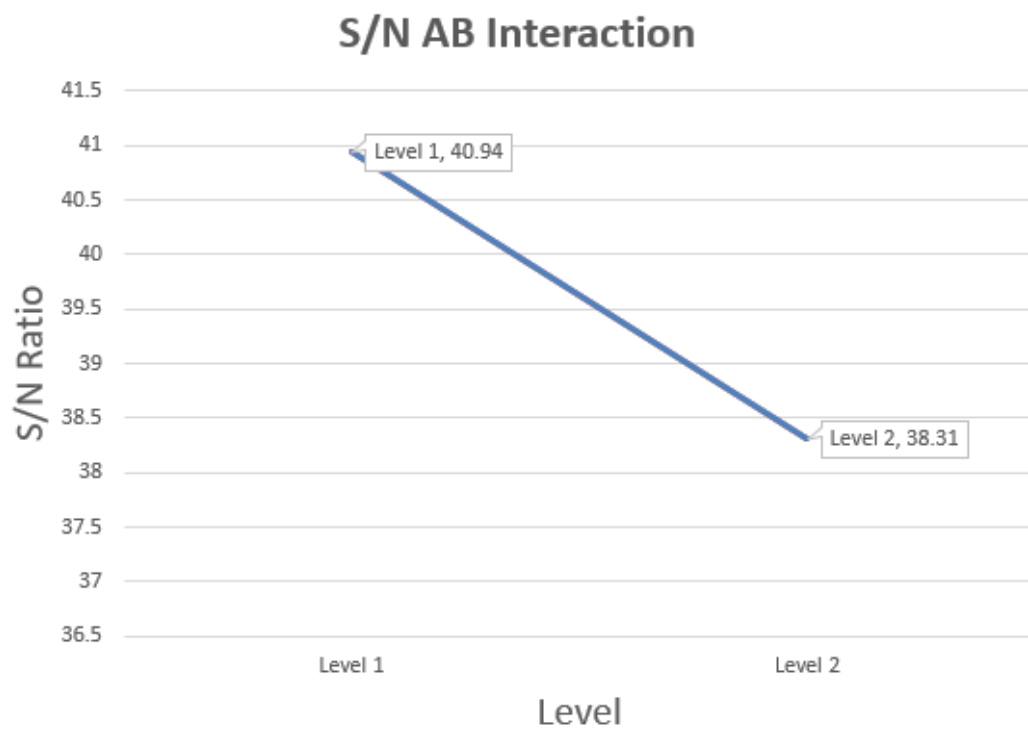


Figure 15 S/N AB Interaction Graph

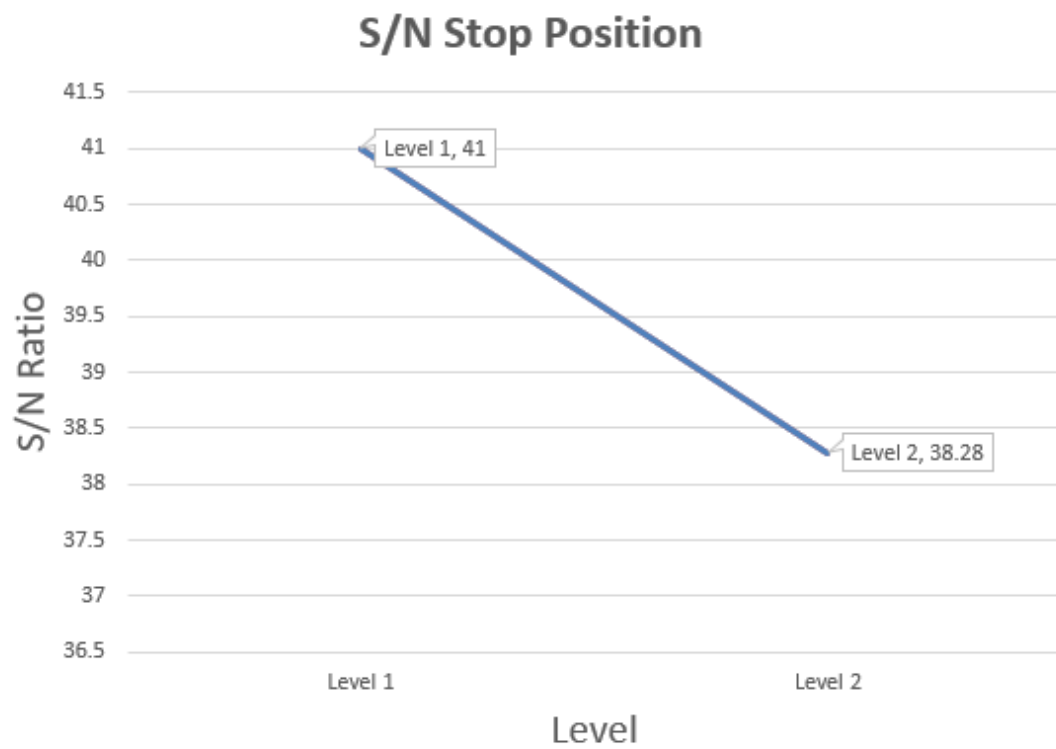


Figure 16 S/N Stop Position Graph

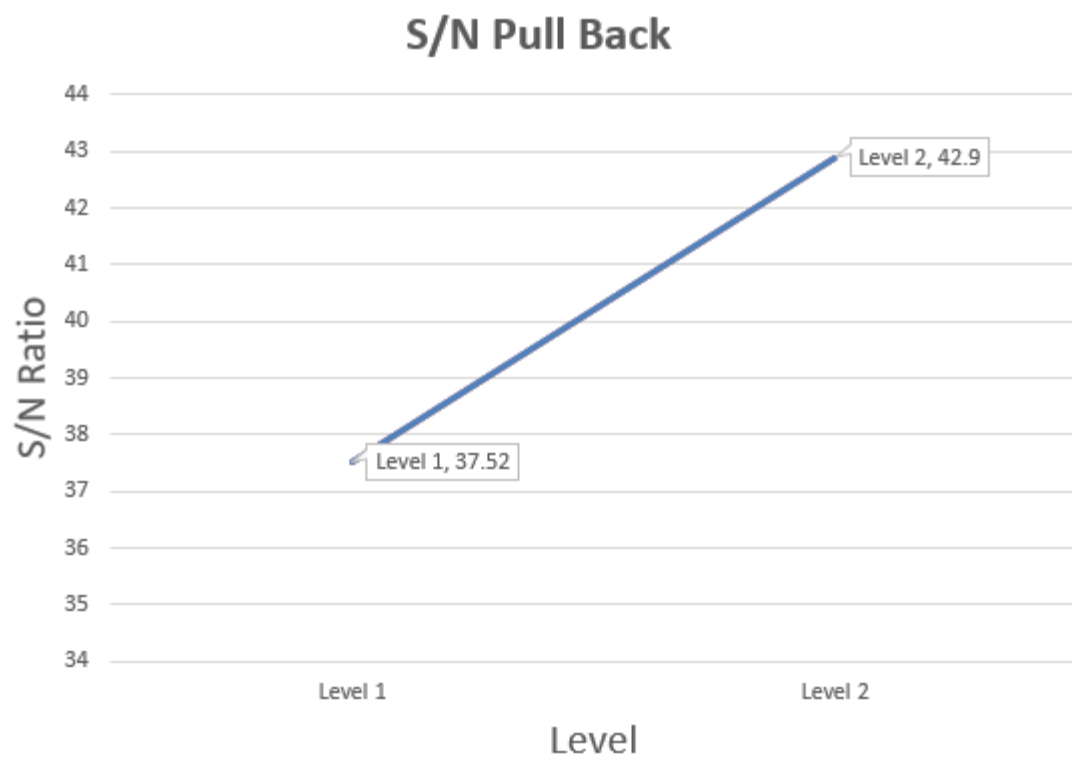


Figure 17 S/N Pull Back Graph

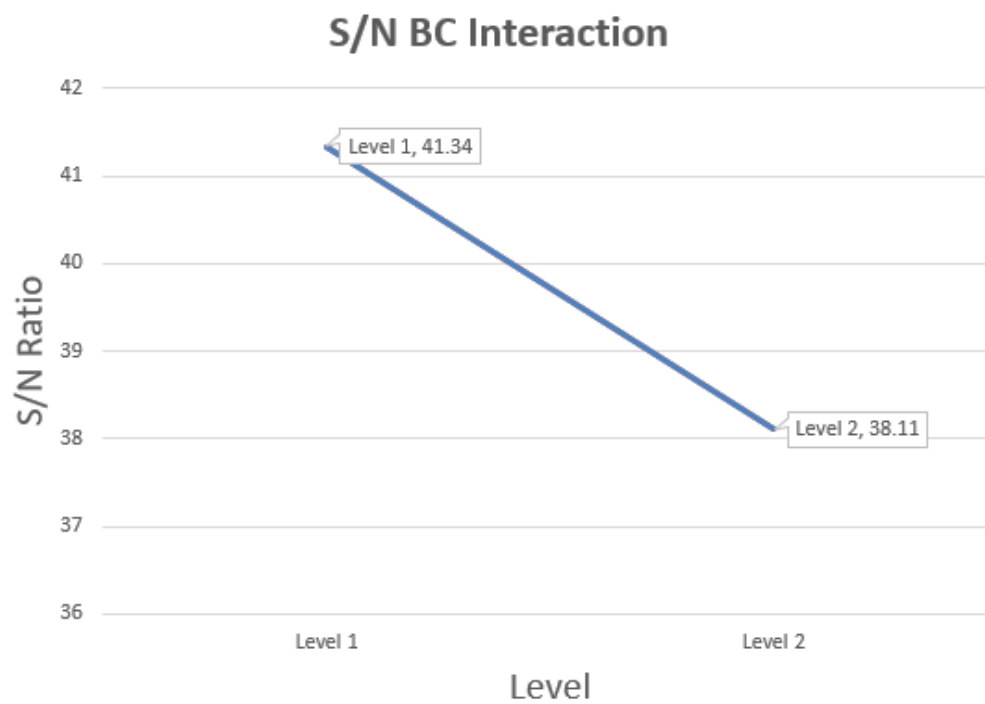


Figure 18 S/N BC Interaction Graph

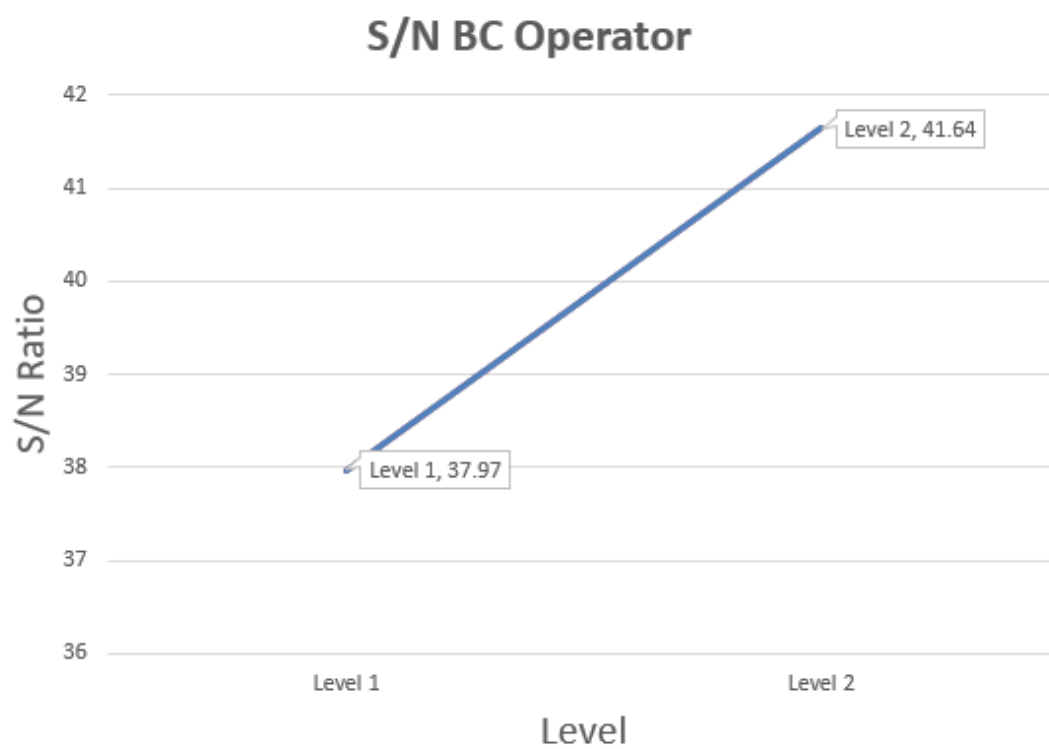


Figure 19 S/N BC Operator Graph

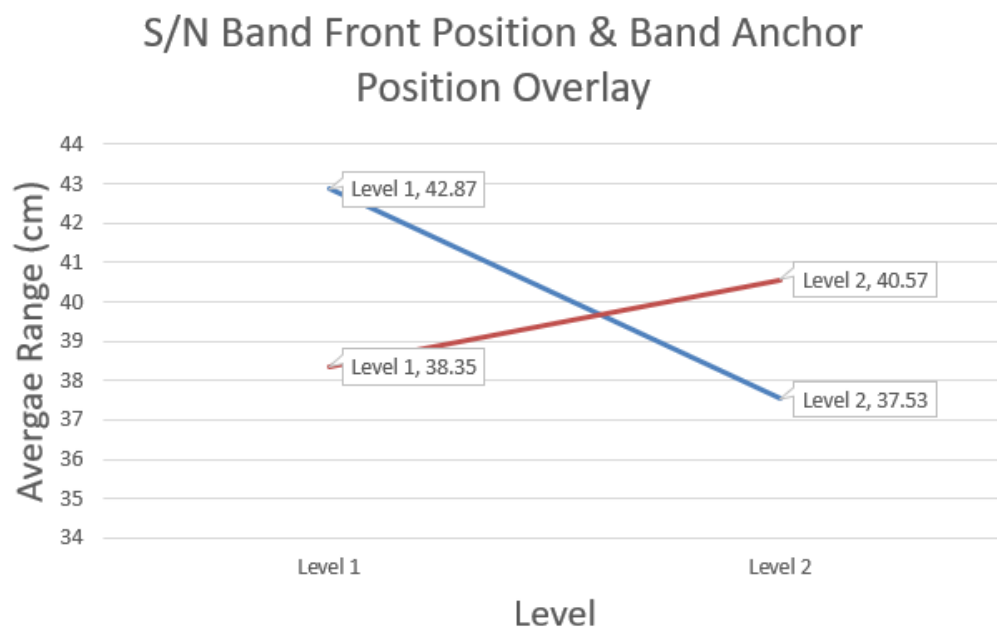


Figure 20 S/N Band Front Position & Band Anchor Position Overlay Graph

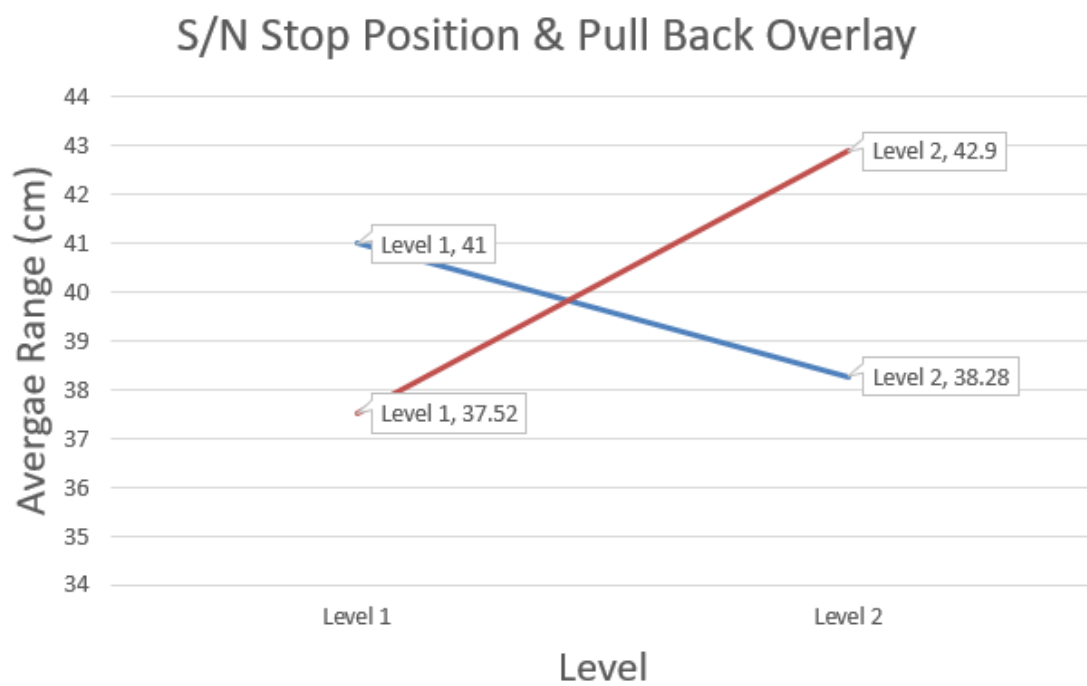


Figure 21 S/N Stop Position & Pull Back Overlay Graph