Application Note
Gaming Trigger With Hall-Effect Sensors

TEXAS INSTRUMENTS

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ABSTRACT

Gaming controllers have numerous input sources enabling players to move their character, leverage equipment, and navigate menus. One of the many controls is a trigger. Whether this trigger provides a single impulse, binary-state response, or variable- magnitude response to the console, a Hall-effect sensor can be used. This document covers how that can be accomplished.

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1 Introduction

Gamers have the pleasure to live vicariously through some digital avatar in a myriad of different environments ranging from a soldier in World War II, to a warlock in some enchanted land, or even a vigilante street racer in a dystopian world. Presently, players must use a hand-held controller to interface with these digital worlds. One of the many controls available to these gamers is the trigger. This document provides the basic operating principles and shows the design process for one possible version of a gaming controller trigger. Challenges in the design process are also documented.

Figure 1-1 summarizes the design flow presented in this document.

```
           ┌─────────────────────┐
           │   Trigger Control   │
           │       Chosen        │
           └─────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │    Choose general Mechanical Method   │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │  Choose general magnetic sensing Method│
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │       Choose Magnet for Form Factor   │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │ Find necessary displacement for various devices │
   │            through simulation         │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │               Prototype               │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │               Bench Test              │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │    Assess and understand sources of error │
   └──────────────────────────────────────┘
                      │
                      ▼
   ┌──────────────────────────────────────┐
   │ Postprocessing to translate output voltage to position │
   └──────────────────────────────────────┘
```
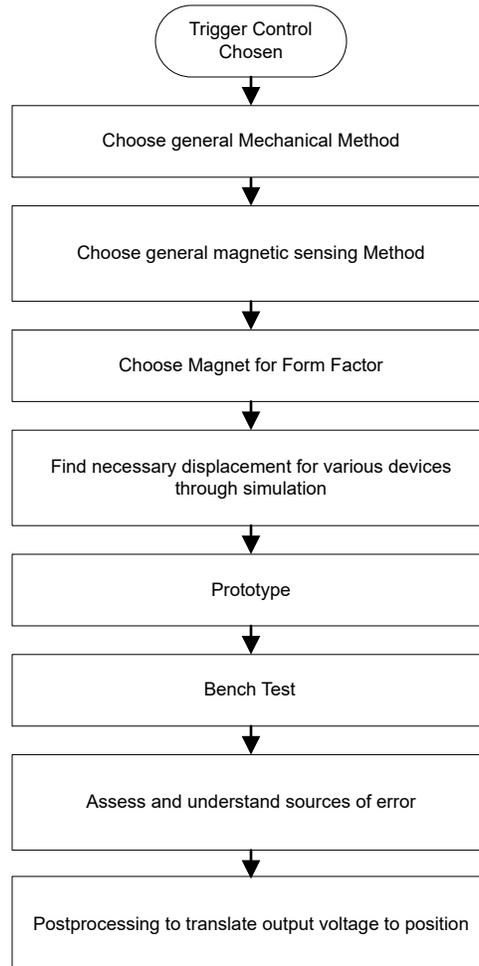
Figure 1-1. Trigger Development Flow

2 Mechanical Implementation

The basic mechanical structure has a direct influence over the range of motion of the magnets and dictates what sensor and magnet pairings are viable. In Figure 2-1, the method 1 trigger slides to the left when the user applies pressure and slides back to the right when the user releases. As illustrated in method 2, the trigger rotates about a hinge when the user applies or releases pressure. This application note focuses on method 2; however, for more information on method 1, see the *HALL-TRIGGER-EVM User's Guide*
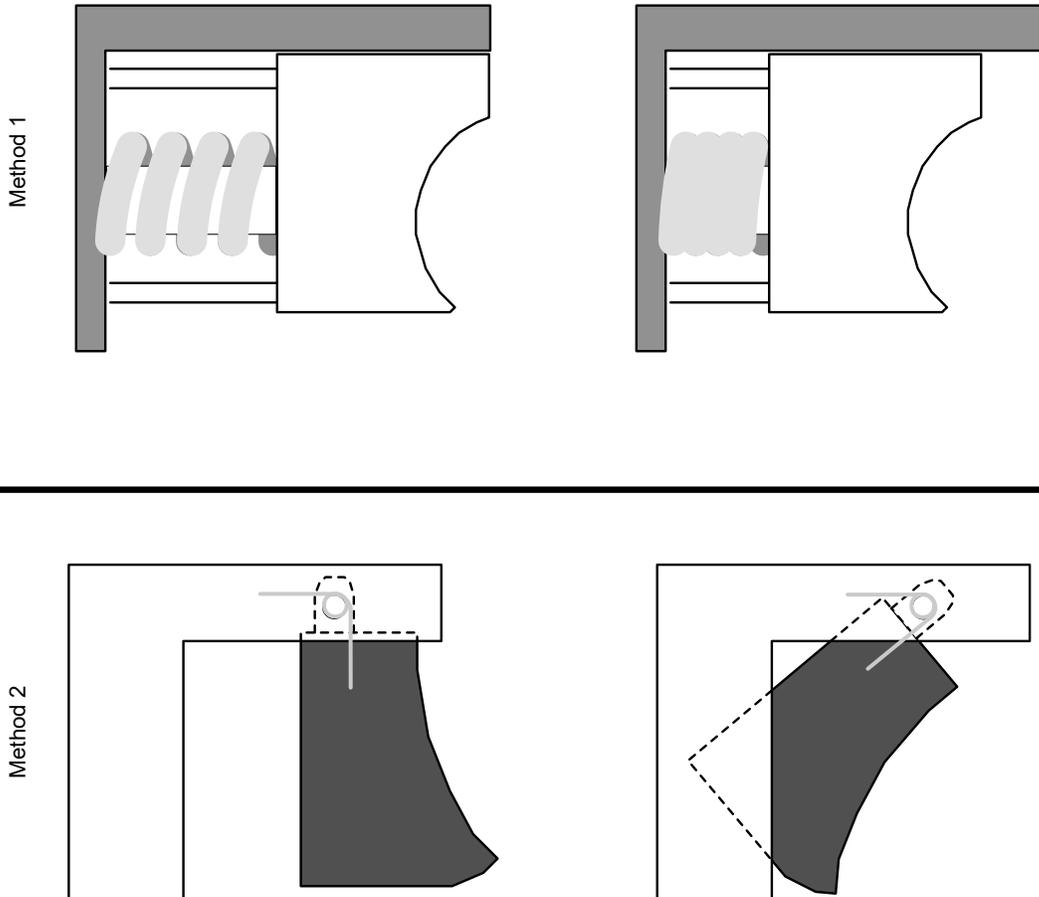
Figure 2-1. Mechanical Options

3 Magnetic Implementation

The magnetic implementation corresponds to the type of magnet, the path of motion, and the orientation of the magnet and sensor relative to each other. Figure 3-1 shows two of many possibilities that can be used. In the first example a cylindrical magnet rotates at the hinge of the trigger, while in the second example a block magnet or cylindrical magnet moves in an arc some radius from the hinge. Due to typical magnet sizes and spatial constraints, the second magnetic implementation is pursued.
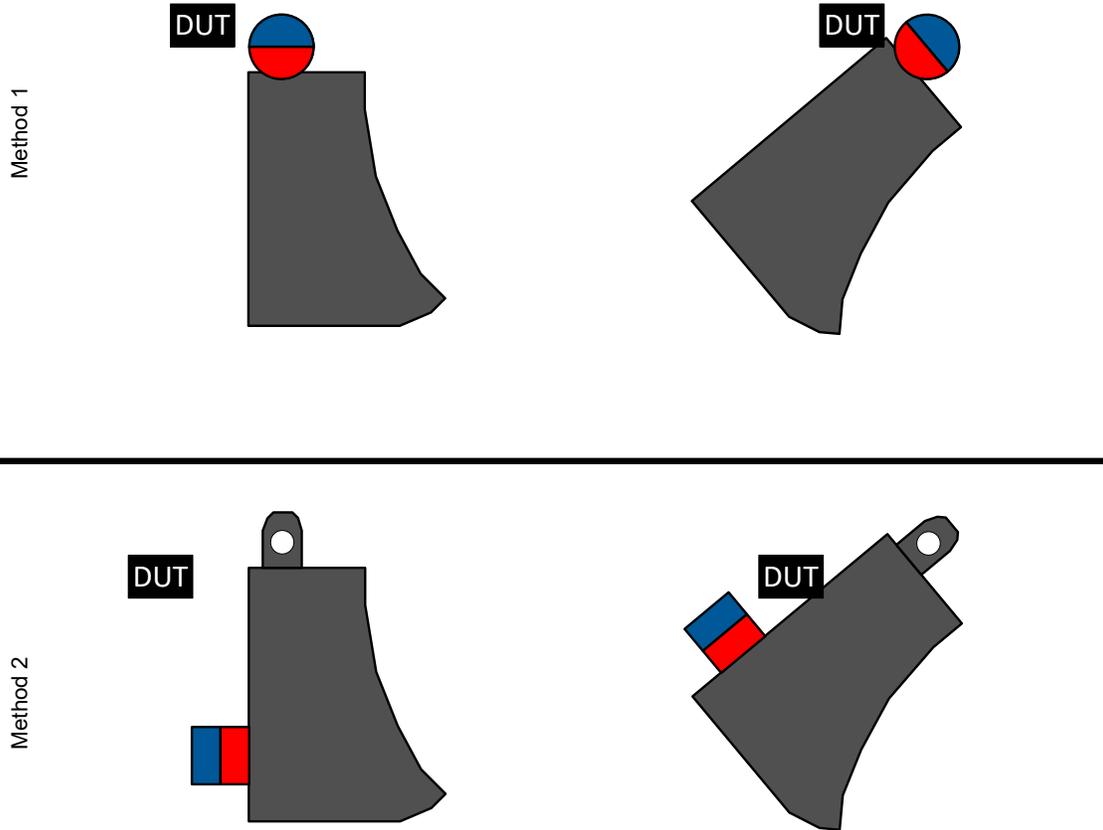
Figure 3-1. Magnetic Options

4 Magnet Sensor Placement

The goal of the design presented in this application report, is to have the output range from mid-supply to either the supply or ground rail over the full range of motion like the top middle plot in Figure 4-1. If the output in the default rest-state angle is well above mid-supply and the output rails to the supply with minimal movement like in the left plot, the magnet is too close to the sensor. Conversely, if the output barely changes over the range of movement like the right plot, the magnet is too far away. Yet another possibility is that the sensor sees the same voltage potential at two different angles like in the bottom figure. For a single Hall-element sensing design this is something to avoid as the two angles are indistinguishable to the sensor. For this scenario, consider reorienting the sensor or the magnet.
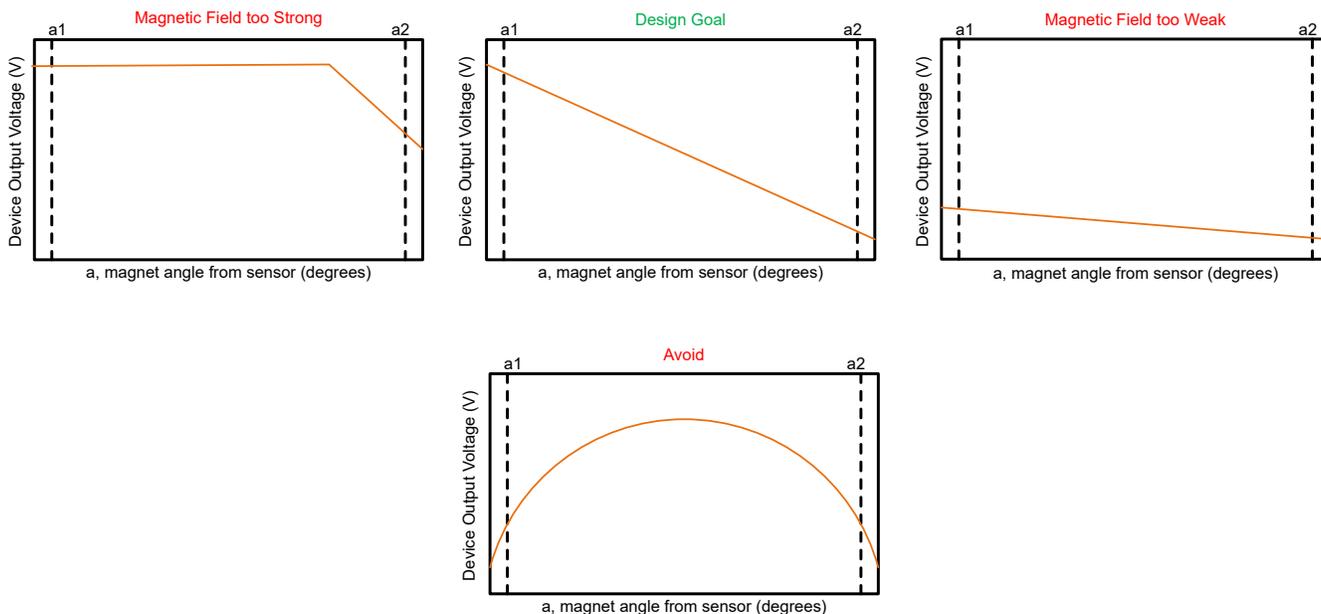
Figure 4-1. Output Example Plots

The key bounding constraints for this design are likely to be space and cost, with cheaper and smaller magnets being desired. Small magnets are desired from the standpoint that you have a small controller enclosure filled with other sensors, haptic motors, power converters, wireless transceivers, and processing circuits. Therefore, minimal space is allocated to the trigger and the magnet needs to fit within the trigger. Smaller magnets have less magnetic flux and cheap magnets like ferrite magnets have the least amount of magnetic flux. Consequently, the sensor needs to be near the magnet.

How close the magnet needs to be can be determined through iteration. Fortunately, there are tools for example, *TI's Magnetic Sensing Proximity Tool* shown in Figure 4-5 that allow the user to test multiple cases before proceeding to bench builds. For the final test iteration, a 3/8-in (9.525-mm) diameter by 1/8-in (3.175-mm) thick cylindrical ceramic-ferrite magnet that fits in the trigger assembly as shown in Figure 4-2 was selected. After clicking *Calculate B-Field & Vout*, the tool prompts users to enter more magnet information such as in Figure 4-4, if *Custom* was selected for *Magnet Material*. In this entry form, relative permeability (μ_r) and coercivity (H_c) are required. These values can be determined from magnet manufacturer specifications and Equation 1.
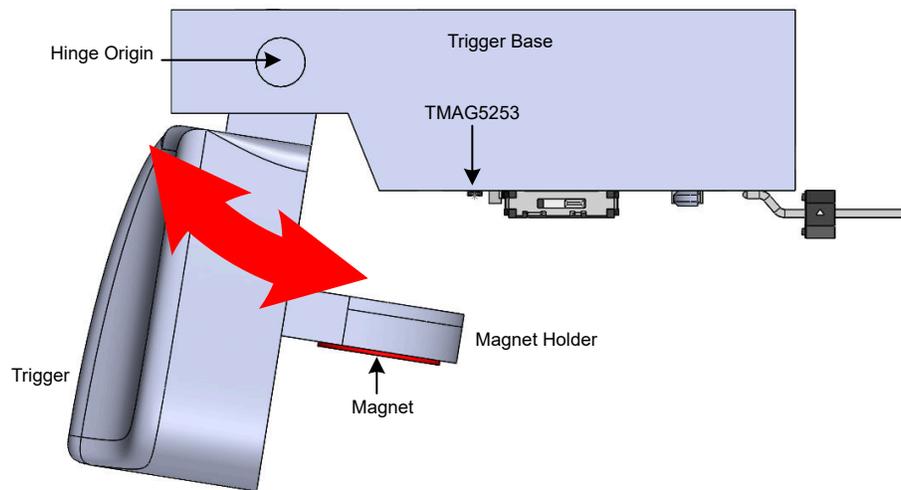
Figure 4-2. Trigger Module

To simplify assessment within the tool, the trigger was reoriented to match the orientation of tool placement specifications. The trigger implementation chosen for this application has a hinge movement that moves between a range of angles that can be specified in the tool entry fields a1 and a2 as indicated in Figure 4-3. Based on ergonomics, a range between 65° and 110° was set. Aside from angle range, Figure 4-3 indicates that multiple additional specifications were required for proper evaluation. These specifications correspond to dimensions outlined in Figure 4-5. Arc Radius, Sensor Z-Offset, and Magnet Z-Offset are all relative to the hinge origin, while X-offset and Y-offset are relative to the device origin. Upon specifying relative magnet and sensor locations, a device can be selected. In this case the TMAG5253 is considered, because this device is a lower power device that can be enabled and disabled.
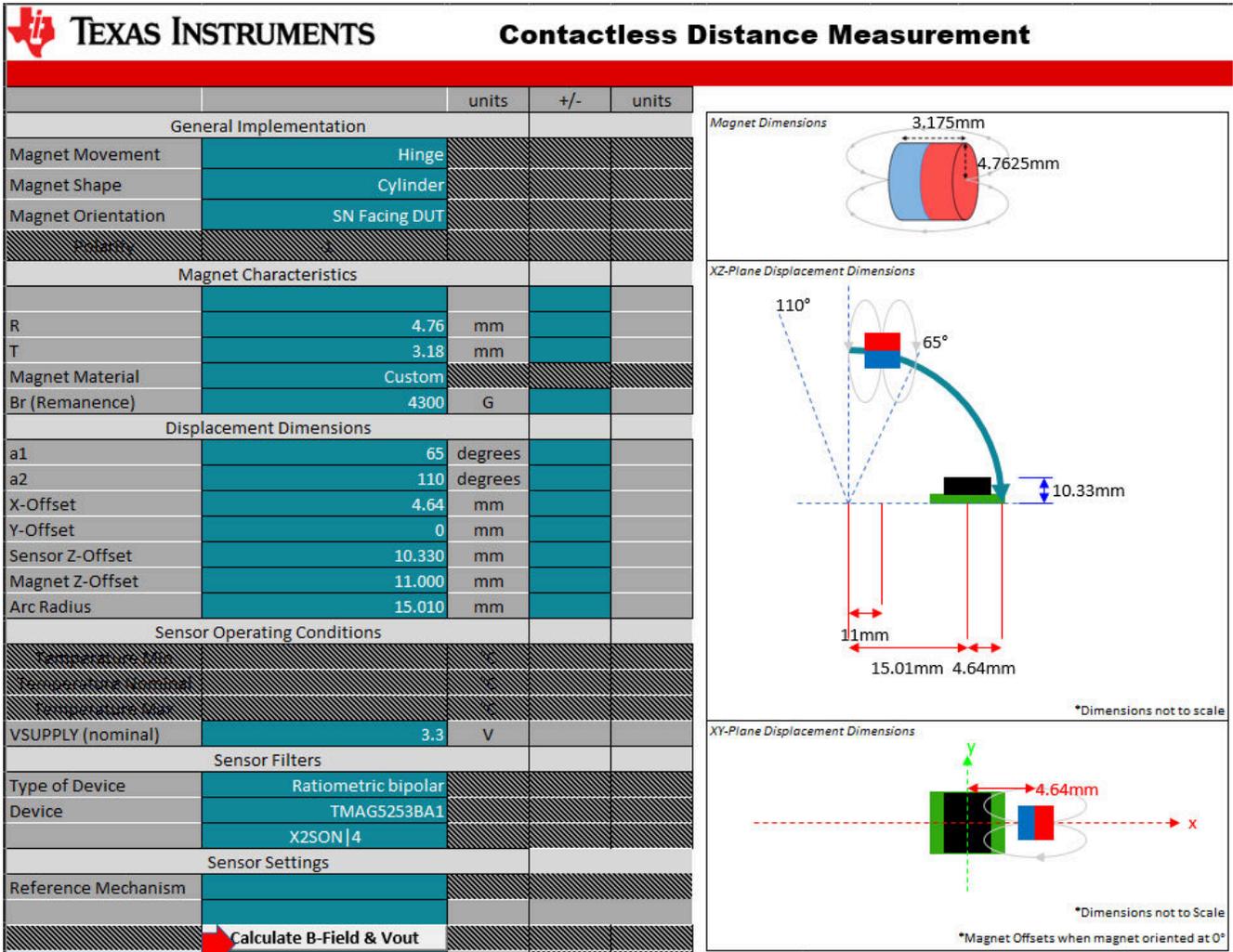
Figure 4-3. Tool Input
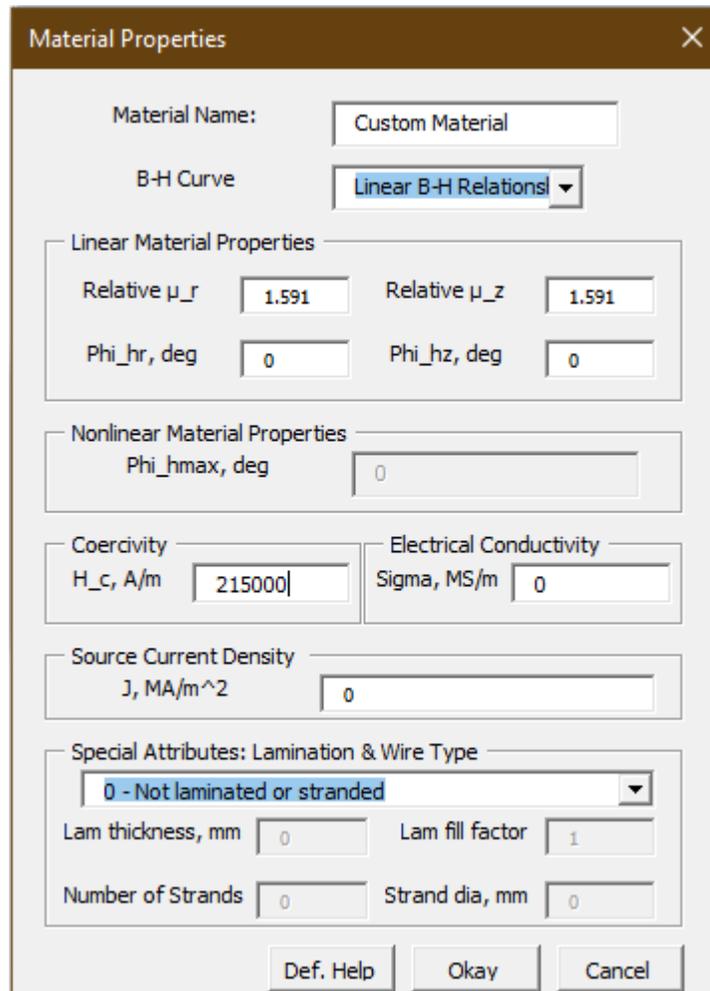
Figure 4-4. Magnet Entry

$$B_r = \mu_r \mu_o H_c \qquad (1)$$
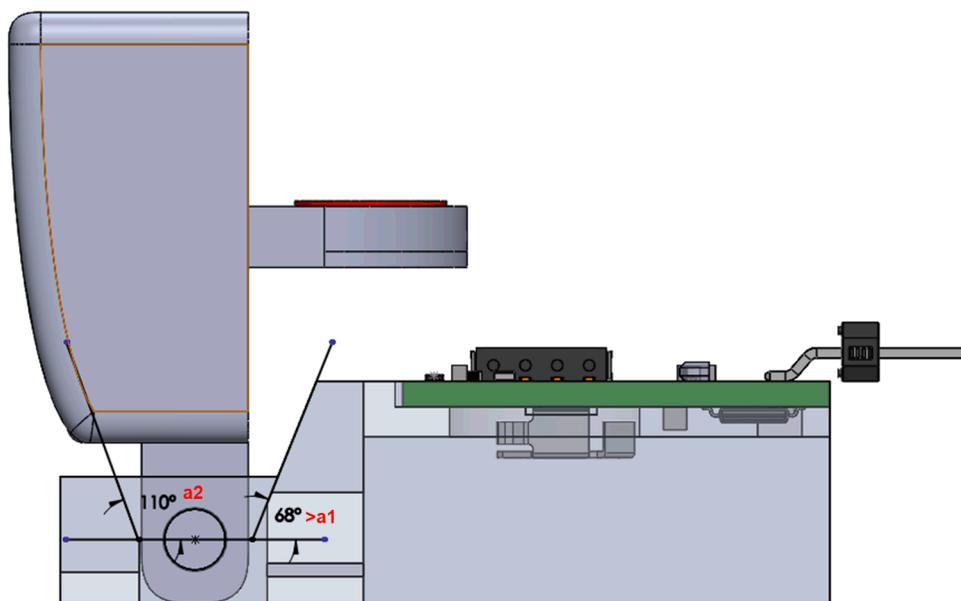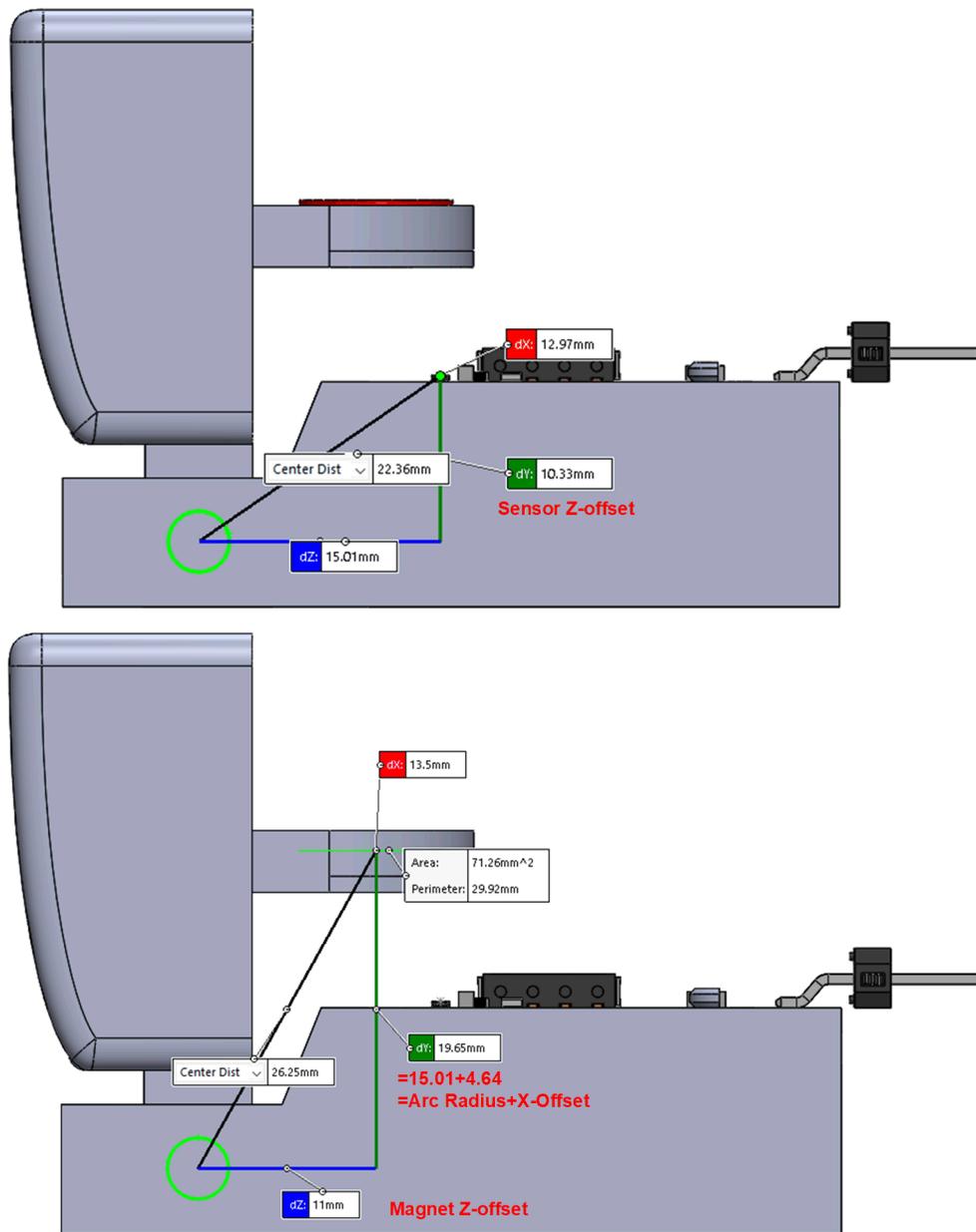
Figure 4-5. Magnet Device Relative Placement

Simulation results in Figure 4-6 indicate that this design is outside the desired design goal since the output is not linear and the output rails to the supply prematurely. At this point there are a few options. These options include modifying various mechanical parameters, modifying the magnet, or trying a different sensitivity variant of the device. Spacing the magnet further away from the device decreases the field observed at angles closer to a1; however, that pulls the device into a region where larger angles near a2 have subtle to no difference. A less sensitive device with a broader measurement range can be used. However, since there is some flexibility in mechanical design, the lower angle bound was reduced to around 75°. Linearity for this particular range and type of motion is difficult to achieve and the output values between 79° and 110° do not repeat or lead to aliasing; therefore, advancing to the next stage of development is reasonable.
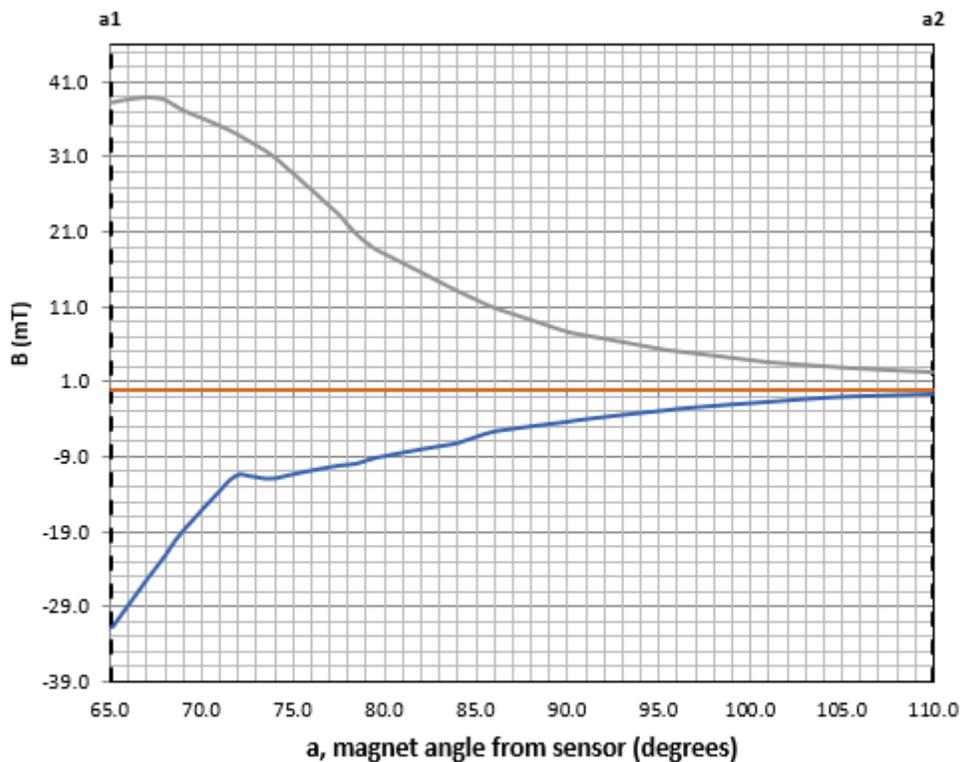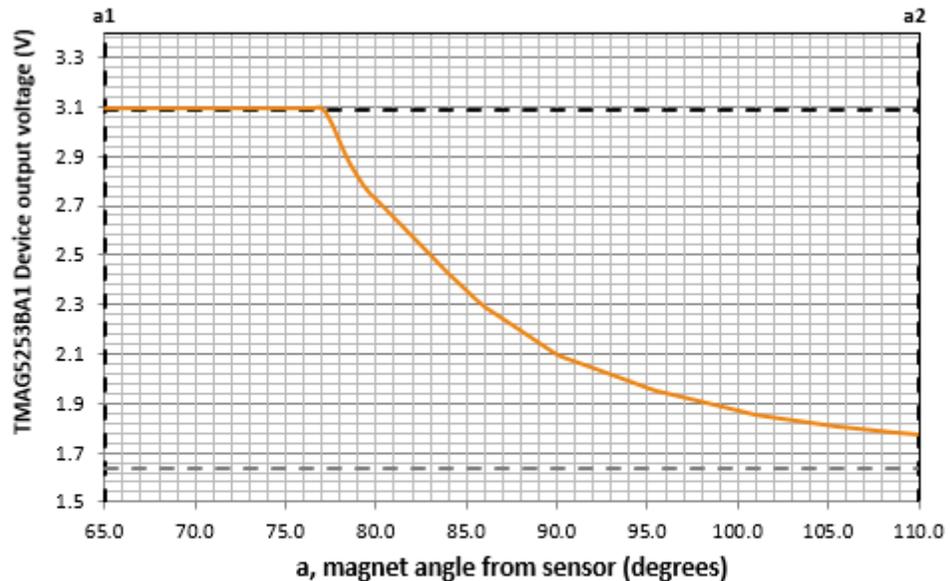
Figure 4-6. Simulation Output

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5 Prototyping and Bench Testing

While simulation can be helpful for the preliminary design and assessing feasibility, prototyping and bench testing is necessary for verifying actual performance. Simulation is preferred and does not have all the necessary parameters to exactly match real-world test cases. Bench tests reveal some of the possible discrepancies from preferred simulations to expect from the manufacturing and assembly process

The design presented in this application note is what was used for the TMAG5253EVM. Figure 5-1 shows the test setup used to validate the TMAG5253EVM trigger design. In this setup, the phone captures a video of the trigger moving while a computer and portable oscilloscope captures TMAG5253 device output. Both video files are then synced through an audio impulse. In the phone-captured video, a red line drawn through the hinge origin is compared against a protractor centered at the hinge origin.
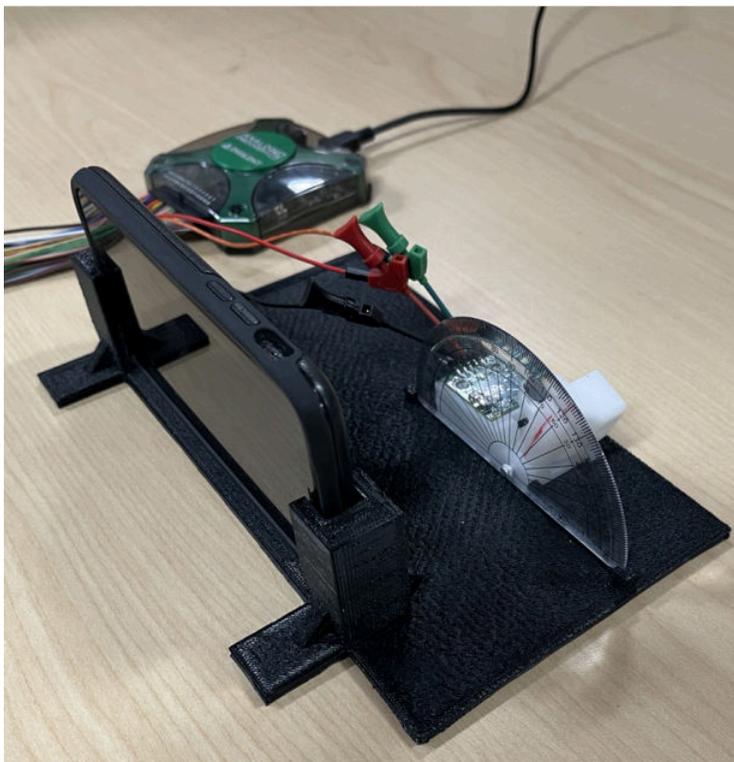
Figure 5-1. Measurement Setup

From the synced video files, voltage corresponding to trigger angle was determined as shown in Figure 5-2.
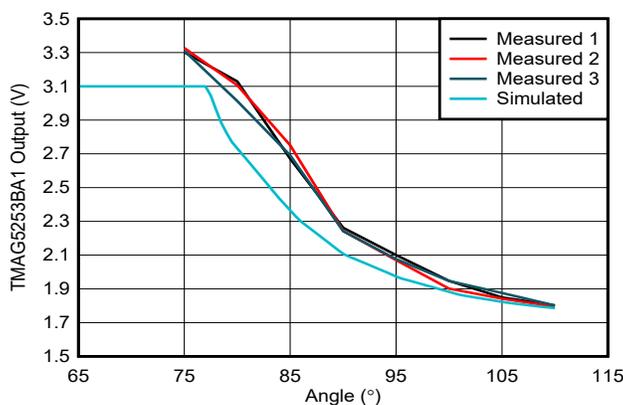
Figure 5-2. Measured vs Simulated

6 Error Sources

There are several possible sources of error, many of which correspond to fabrication and assembly. In the process of evaluating on the bench, such error sources are easier to identify, thereby making bench testing a good and necessary practice to embrace before proceeding to mass production. The following list shows all possible error sources identified for this particular design including the ones accounted for in the preliminary design:

- Fabrication limitation and mechanical tolerance
- Operating outside of the linear region
- Device offsets
- Roll, yaw, and pitch
- Magnet variation
- Device variation and temperature drift
- External fields
- Nearby material influence
- Bench setup error
- Supply tolerance
- Measurement precision

For more in depth review of each of these error sources, see the *HMI Rocker Switch With Hall-Effect Switches* application note.

7 Post Processing

After finalizing the trigger hardware, a method of translating the TMAG5253 device output into the corresponding angle needs to be determined. Assuming the device and mechanical tolerances are sufficiently small, use a look-up table or a regression equation. In both methods, several trigger systems must be characterized to determine what voltage corresponds to the angle. Then an average curve can be generated based upon the sample measurements. As shown in Figure 7-1, the averaged data points serve as the look-up values, and any value in between indicated by the dotted line is interpolated. More data points can be required to accurately predict a nonlinear output.
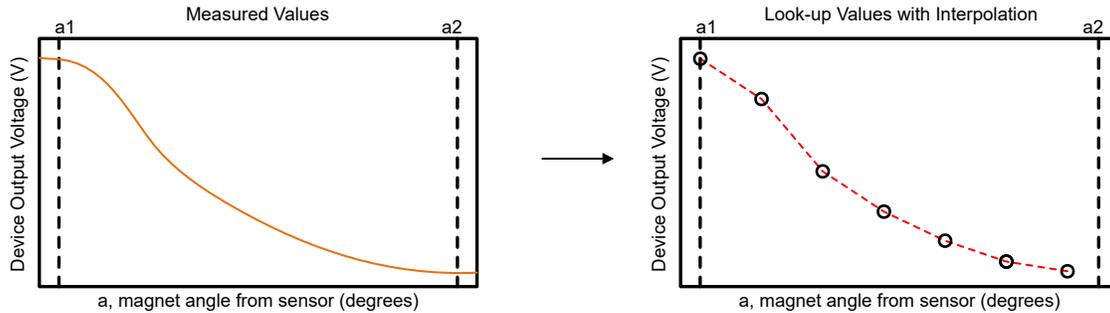
Figure 7-1. Look-up Table Method

Since look-up tables can take up more memory than desired, the regression equation approach is a viable option. A regression equation can be as simple as a linear equation or as complex as a quartic equation. Figure 7-2 shows an examples of using linear, quadratic, and cubic regressions to recreate the measured curve. Beside each curve is the corresponding equation.

$$aV_{out} + b = angle$$

$$aV_{out}^2 + bV_{out} + c = angle$$

$$aV_{out}^3 + bV_{out}^2 + cV_{out} + d = angle$$
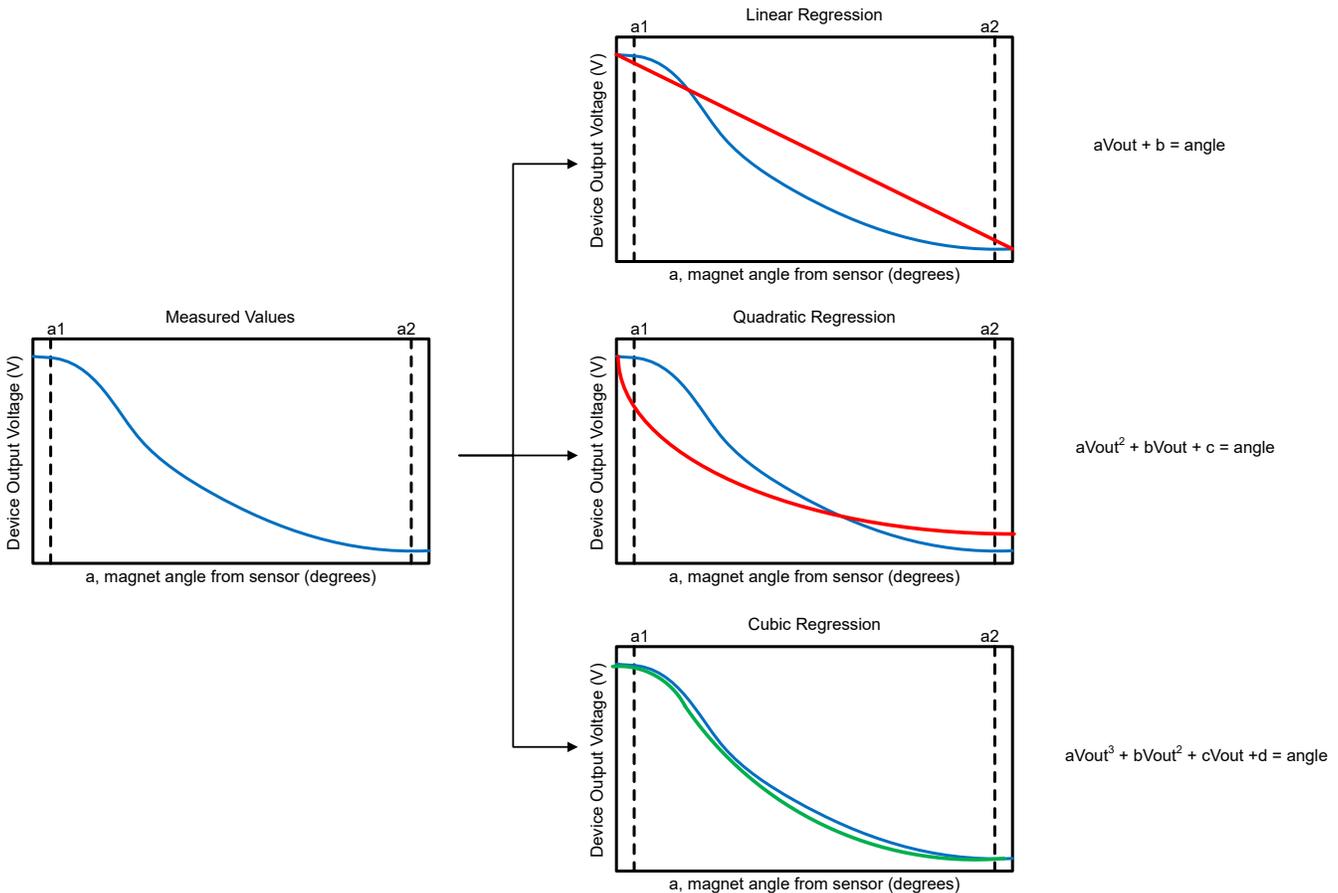
Figure 7-2. Regression Method

For the trigger design featured here, which has one plot bend due to non-linear behavior of magnetic field magnitude and another plot bend for the output exceeding the linear range of the output voltage ($V_{OUT} > V_L$), a cubic regression equation seems most appropriate. To get the cubic regression equation, a system of equations like Equation 2 through Equation 5 needs to be solved. Since the angle is the unknown that needs to be solved for in the application, voltage can be substituted for *x*, while angle can be substituted for *y*, and *n* equals the number of data points collected. Table 7-1 shows the values used to calculate the summation values, while Table 7-2 shows the summation values used in Equation 2 through Equation 5. With coefficients provided in Table 7-2, coefficients *a* through *d* can be solved in Microsoft® Excel® with Equation 6.

$$a\sum x_i{}^6 + b\sum x_i{}^5 + c\sum x_i{}^4 + d\sum x_i{}^3 = \sum x_i{}^3 y_i \qquad (2)$$

$$a\sum x_i{}^5 + b\sum x_i{}^4 + c\sum x_i{}^3 + d\sum x_i{}^2 = \sum x_i{}^2 y_i \qquad (3)$$

$$a\sum x_i{}^4 + b\sum x_i{}^3 + c\sum x_i{}^2 + d\sum x_i = \sum x_i y_i \qquad (4)$$

$$a\sum x_i{}^3 + b\sum x_i{}^2 + c\sum x_i{}^1 + d\sum n_i = \sum y_i \qquad (5)$$

Table 7-1. Regression Related Values 1

Angle (degrees)	Output (V)	Output^2	Output^3	Output^4	Output^5	Output^6	Output Angle	Output^2 Angle	Output^3 Angle
110	1.799433	3.23796[1]	5.82649[2]	10.484387	18.86596	33.94803	197.9376	356.1756[3]	640.9143[4]
105	1.85587	3.444241	6.392052	11.8627	22.01577	40.85833	194.866	361.6453	671.1655
100	1.932033	3.732753	7.211803	13.93344	26.91988	52.0101	193.2033	373.2753	721.1803
95	2.082433	4.33652	9.030532	18.80548	39.16116	81.5505	197.8312	411.9702	857.9005
90	2.248933	5.057701	11.37443	25.58034	57.52848	129.3777	202.404	455.1931	1023.699
85	2.705	7.317025	19.79255	53.53885	144.8226	391.7451	229.925	621.9471	1682.367
80	3.0829	9.504272	29.30072	90.33119	278.482	858.5323	246.632	760.3418	2344.058
75	3.313167	10.97707	36.36887	120.4961	399.2238	1322.695	248.4875	823.2805	2727.666

(1) Result of column 2, cell 1 (1.799433), raised to the power of 2
(2) Result of column 2, cell 1 (1.85587), raised to the power of 3
(3) Result of column 8, cell 1 (197.9376), raised to the power of 2
(4) Result of column 8, cell 1 (197.9376), raised to the power of 3

Table 7-2. Regression Related Values 2

Row	a	b	c	d	Right-Side Terms
1	$\sum x_i{}^6$ = 2910.717061	$\sum x_i{}^5$ = 987.0197	$\sum x_i{}^4$ = 345.0326	$\sum x_i{}^3$ = 125.2975	10668.95
2	$\sum x_i{}^5$ = 987.0197	$\sum x_i{}^4$ = 345.0326	$\sum x_i{}^3$ = 125.2975	$\sum x_i{}^2$ = 47.60755	4163.829
3	$\sum x_i{}^4$ = 345.0326	$\sum x_i{}^3$ = 125.2975	$\sum x_i{}^2$ = 47.60755	$\sum x_i$ = 19.01977	1711.287
4	$\sum x_i{}^3$ = 125.2975	$\sum x_i{}^2$ = 47.60755	$\sum x_i$ = 19.01977	$\sum n_i$ = 8	740

1. $x_1{}^n$=output^n at 110°, $x_2{}^n$=output^n at 105°, etc.

$$\mathrm{MULT(MINVERSE(a1:d4), right{-}side\ terms1:right{-}side\ terms\ 4)} \qquad (6)$$

From the values in Table 7-2 and the Excel formula Equation 6, the coefficients for Equation 7 can be calculated. Figure 7-3 provides a comparison between our average measured values and equation generated angle values for voltage outputs between 1.7 V and 3.3 V.

$$-25.5528 \times \mathrm{output}^3 + 206.8976 \times \mathrm{output}^2 - 564.915 \times \mathrm{output} = \mathrm{angle} \qquad (7)$$
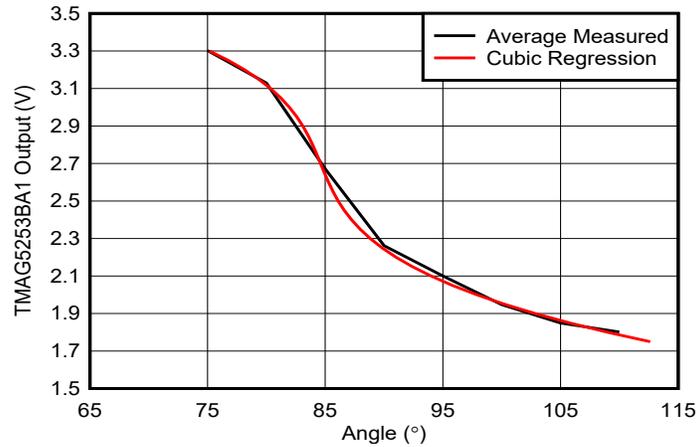
Figure 7-3. Regression Fit

8 Summary

This application note covered the process for designing a trigger with Hall-effect sensors. This process started with covering the mechanical implementation of the trigger and progressed through selecting a device based upon calculations performed in *TI's Magnetic Sensing Proximity Tool*, and concluded with some post-processing techniques to map device output voltage into angle. After the preliminary theoretical design process, prototyping and bench measurement were discussed. One key insight is that there are potentially many different methods to each step of the design, whether it is the mechanical operation, the magnet and sensor pairing, relative placement, or post-processing technique. The second key insight is that there are tools that can be leveraged so that calculation for the various stages can be done expeditiously. The third critical insight is that prototyping is crucial after some rigorous simulation sweeps to better understand errors and possible manufacturing limitations.

9 References

1. Texas Instruments, *HALL-TRIGGER-EVM* user's guide.
2. Texas Instruments, *HMI Rocker Switch With Hall-Effect Switches* application note.

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