



**EIGEL-DANIELSON**  
**INCORPORATED**

*autoEC*®

**Eddy Current Signal Conditioner**



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## INTRODUCTION

The EDI autoEC is a digitally corrected eddy current signal conditioner designed to work with a wide variety of eddy current sensors. The autoEC is easy to setup and calibrate via a USB interface that can work with the Windows™ based software provided by EDI or any simple terminal program. The autoEC can coax high performance from sensors provided by different manufacturers with ease. Once the autoEC is setup only power over the USB connector is required and so a variety of wall plugs with USB adaptors can be used. Both the electronics and sensor can also be independently temperature compensated in-situ to reduce any temperature sensitivity.

The autoEC is also available in an OEM configuration with no enclosure.

### ***Getting Started***

#### *Install the Driver Software*

You will need to run the setup.exe file under the installation. You may also need to install the FTDI drivers by running the **CDM v2.12.06 WHQL Certified.exe** FTDI driver installation. FTDI drivers are amongst the most popular and usually Windows will have it already available or can install it if necessary.

#### *Connect the USB cable*

A USB 2.0 connection is required as it also powers the autoEC.

#### *Connect the Sensor*

The sensor is connected to the SMA connector.

#### *Calibrate the Sensor*

The sensor must be calibrated before it will function properly. The calibration section of this manual for calibration examples. The raw output is 0-100000 for the calibrated range whatever voltage range is selected. This can be scaled for the purposes of software readout over the USB interface.

#### *Connect the Outputs*

Connect either the analog voltage output, current output, or use the USB interface. For the analog voltage and current output, output ranges (i.e. 0-5V,  $\pm 5V$ , 0-10V,  $\pm 10V$ , 0-20mA, or 4-20mA) can be selected using the front panel menu.

## CONNECTIONS

The autoEC I/O connections are all through a 6 pin removable terminal block. The autoEC sensor is connected through an SMA coaxial connector. A USB connection is made for power and communication. *In the OEM versions that are board only an optional 2 pin header can be installed under the USB and the unit can be powered from it. When this is the case the unit can still communicate via USB for setup and calibration but must always be powered from the 2 pin header.*



Pin	Name	Function
1	Vout	Voltage Output (0-5, $\pm 5$ , 0-10, $\pm 10$ )
2	Gnd	Ground
3	Iout	Current Loop Output (0-20mA, 4-20mA)
4	IO	IO Bit for special functions -- standard setup for Autozero when grounded.
5	Gnd	Ground
6	Relay	Solid State Relay Connection

**Table 1 Terminal Block Pin-Out**

### ***Volt Out Setup***

This option allows selection of the voltage output range from the system.

The actual voltage will go 1% above or below the voltage output range selected if the sensor is above or below the calibrated range.

### ***mA Out Setup***

This option allows selection of the current output range from the system.

The actual current will go 5% above or below the current output range selected if the sensor is above or below the calibrated range. In the case of 0-20mA output, it will not go below zero. *Note the current output is not available with settings over 10000 samples per second.* Consult the factory if this is a requirement.

### ***Cal Setup***

This selection allows linearization calibration and temperature compensation. With the exception of the 2 Pt. or 3 Pt. Adjust (reference 4.8) all other calibration methods will zero out the temperature compensation coefficients and any offset.

## ***Linearization Options***

3 options are available for linearization calibration, 2 point, 6 point and 21 point.

Note: Performing a linearization calibration after a temperature compensation calibration will void the temperature compensation calibration. All linearization calibrations begin by locating the sensor at the maximum distance it will be from the target during operation. This is typically the sum of the offset distance and full scale range.

### ***2 Point Calibration***

The 2 point calibration is useful if either linearity of the output is not a concern or if the sensor is operated over a very short range. Ranges less than 10% of the standard range (a standard range is normally 33% of the sensor diameter) typically will result in good linearity. For ranges below 5% of the standard range; this is the recommended method.

To perform a 2 Pt calibration, the sensor needs to be position at MAX distance from the sensor face (i.e. full scale) so that it can optimize for a given sensor. After that, the sensor needs to be positioned at only the offset (MIN) and full range (MAX) positions. *Any previous temperature compensation calibration will be voided when a 2 Pt. calibration is performed.*

### ***6 Point Polynomial Calibration***

The 6 point polynomial cal fits a 5th order polynomial through the data points to linearize the sensor output. In most cases this method works very well though there can be exceptions.

The sensor needs to be positioned at MAX distance from the sensor face (i.e. full scale) so that it can optimize for a given sensor. After that the sensor needs to be positioned at offset (MIN) and then at 20%, 40%, 60%, 80%, and 100% of the range to complete the calibration. *Any previous temperature compensation calibration will be voided when a 6 Pt. calibration is performed.*

### ***21 Point Piecewise Linear Calibration***

This calibration will result in the best performance. It is a 21 point piecewise linearization method. This option works best if the curve is too oddly shaped for a polynomial to fit well.

The sensor needs to be positioned at the MAX distance from the sensor face (i.e. full scale) so that it can optimize for a given sensor. After that, it needs to be positioned in 5% of the range increments from 0-100%. *Any previous temperature compensation calibration will be voided when a 21 Pt. calibration is performed.*

## ***Temperature Compensation***

The autoEC optimizes the sensor for temperature stability and linearity using proprietary algorithms. However, even with this optimization, some residual error exists due to temperature. Temperature stability can generally be improved by a factor of 5-10 using additional steps to temperature compensate the unit. To perform temperature compensation, data from 2 different displacements with 2 different temperatures must be acquired by the unit. The actual displacement does not matter, but the recommended displacements are approximately 10% and 90% of the calibrated range. If the best temperature coefficient is desired at a particular displacement, that displacement should be chosen as one of the displacements used. The temperature compensation algorithm will have the smallest temperature error at that displacement 1 and 2 when the calibration is completed. The 4 required points are:

- D1T1 (Displacement 1, Temperature 1)
- D1T2 (Displacement 1, Temperature 2)
- D2T1 (Displacement 2, Temperature 1)
- D2T2 (Displacement 2, Temperature 2)

The temperature compensation calibration menu controls the order of the 4 points.

When temperature compensation is selected, the display shows a temperature relative to when the calibration process started. It is displayed in degrees Celsius, but is not particularly accurate in terms of absolute temperature.

The first step is to go to D1T1, it does not matter if it is at the 10% or 90% point (or any point) and it does not matter what order you take the two temperature points in (rising or falling temperature). At this displacement, change the temperature of the sensor noting the output on the display. It is best to avoid transients so by heating (or cooling) the sensor it is best to wait until any transients have passed to take the data point. The unit does not care what the actual temperatures used for the calibration are and they do not have to be the same for both displacements. One method is to heat the sensor up some number of degrees, take one data point after any transients have passed, and take the second data point after it has cooled down some. After the two temperature points have been collected at displacement 1, then position the sensor at displacement 2 and take two temperature points again.

If changing the temperature resulted in slight offset and gain errors due to actual position changes, a 2 or 3 point adjustment calibration can be performed. Temperature coefficients are not affected by a 2 point or 3 point adjustment calibration.



## **Advanced Setup**

### ***Digital Filter***

The display is always filtered but the analog outputs (voltage and current) are not. Resolution of these outputs can be increased using a digital filter. The time constant options ( $\tau$ ) will vary slightly depending on the sample rate selected. If the time constant is 0.0 then no filter is used and only the analog filter and the sample rate matter. The time constant displayed is representative of how fast the system will respond to a step function. For example, a time constant of 0.8ms will get to 95% of the step within 3 time constants or 2.4ms.

Reference Appendix G for more specific details on the digital filter.

### ***Sample Rate***

The sample rate of the system can be set anywhere from 1 to 22,500 samples per second. At the higher speeds some features are not available. 10,000 samples per second is the default.

At 10,000 samples per second and higher, communication with the system over the USB port could slow substantially as the processor is busy most of the time servicing the analog outputs. If analog output only is required, slower communications should not be an issue.

At 10,000 samples per second and lower, both analog voltage and current are output simultaneously. Over 10,000 samples per second and higher, either analog voltage or current is output, but not both.

## ***Adjust Output***

If the sensor has been replaced or has been re-installed the output may need a slight adjustment to achieve the accuracy of the original calibration. There are 3 options for doing this: Zero -- which tares the output of the system and requires only one point, 2 point adjustment -- which uses 2 data points (zero and full scale) to readjust the curve to resemble the original calibration, and a 3 point adjustment which uses zero, mid and full scale data to make the adjustment to the calibration curve. *This is only meant for minor changes caused by new sensors of the same type or re-installation. It is not meant for more major changes to the range or large changes to the offset from the original calibration.*

### *Zero Output*

This will set the displayed output of the system to zero. If a unipolar voltage output is selected (0-5 or 0-10), output will be set to zero when the button is pressed. If a bipolar voltage output is selected it will reference to 50% (zero for the bipolar output voltage) when the button is pressed.

This does not reset the range, so if a range with a unipolar output at 25% is zeroed, the display may lose 25% of the output range. You can also zero the output by grounding the IO bit on the terminal block.

### *Clear Zero*

This will clear the zero offset and return to the calibrated absolute output.

### *2 Point Adjustment*

The 2 point adjust makes a slight adjustment to an existing calibration. It allows for correction of installation or slight loading errors in gain and offset. For this calibration the sensor must be positioned at MIN and MAX with data taken at each point. This adjustment does not optimize the output further; it simply corrects scale and offset errors. Temperature coefficients are not changed. It will remove any offset from zeroing the sensor output.

### *3 Point Adjustment*

The 3 point adjust makes a slight adjustment to an existing calibration. It allows for correction of installation or slight loading errors in gain and offset. For this calibration, the sensor must be positioned at MIN, MID, and MAX with data taken at each point. This adjustment does not optimize the output further; it simply corrects scale, offset, and small linearity errors. Temperature coefficients are not changed. It will remove any offset from zeroing the sensor output. This option is used when more accuracy, but not a full calibration is required.

## USB Interface

The USB interface setup allows you to use either the custom GUI supplied by EDI or use a terminal interface. *USB Cables over 2m in length may not work due to the extra voltage drop in the cable.*



### ***USB Packet***

The USB packets are very simple ASCII commands. If the command is preceded by a '\$' then it will only return with data and a carriage return. It may have a more verbose response if the '\$' is not used so that it is easier to use with a dumb terminal program such as HyperTerminal or TeraTerm. All commands are terminated with a carriage return.

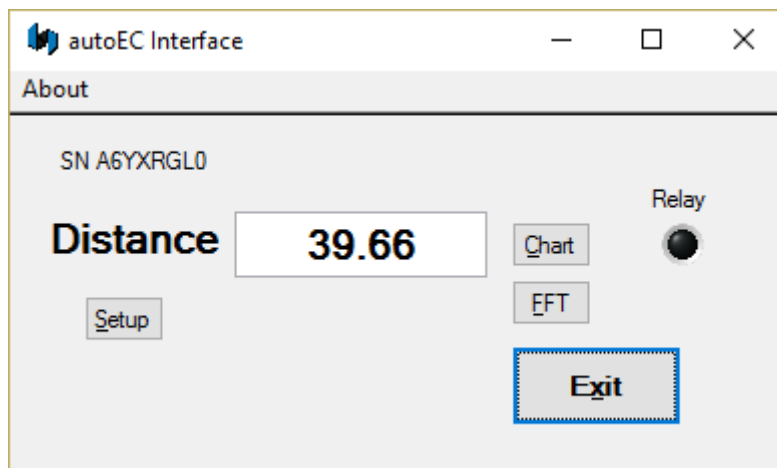
`$<Payload><CR>`

## The autoEC GUI

The autoEC comes with GUI software on the USB stick included with the unit (not included for OEM units). Run the setup.exe in the installer folder and follow the instructions. The GUI software allows you to view the system output over the USB, setup the system, and calibrate.

Note: The FTDI drivers may need to be installed. You will need to install the run the **CDM v2.12.06 WHQL Certified.exe** file from FTDI if they are not already installed. You can download the latest FTDI drivers at [www.ftdichip.com](http://www.ftdichip.com) under drivers/d2xx or driver/vcp drivers.

**Note:** You can download the latest version of the GUI software from an ftp site. You can get it using some web browsers. For example in Internet Explorer go to the site: <ftp://eigeldanielson.com>. Log in with the username [products@eigeldanielson.com](mailto:products@eigeldanielson.com) and the password sensors. The latest version of the autoEC software will be located under the autoEC software. If you click alt/View/View Site in Windows Explorer you will be able to drag the software to a folder in your system.

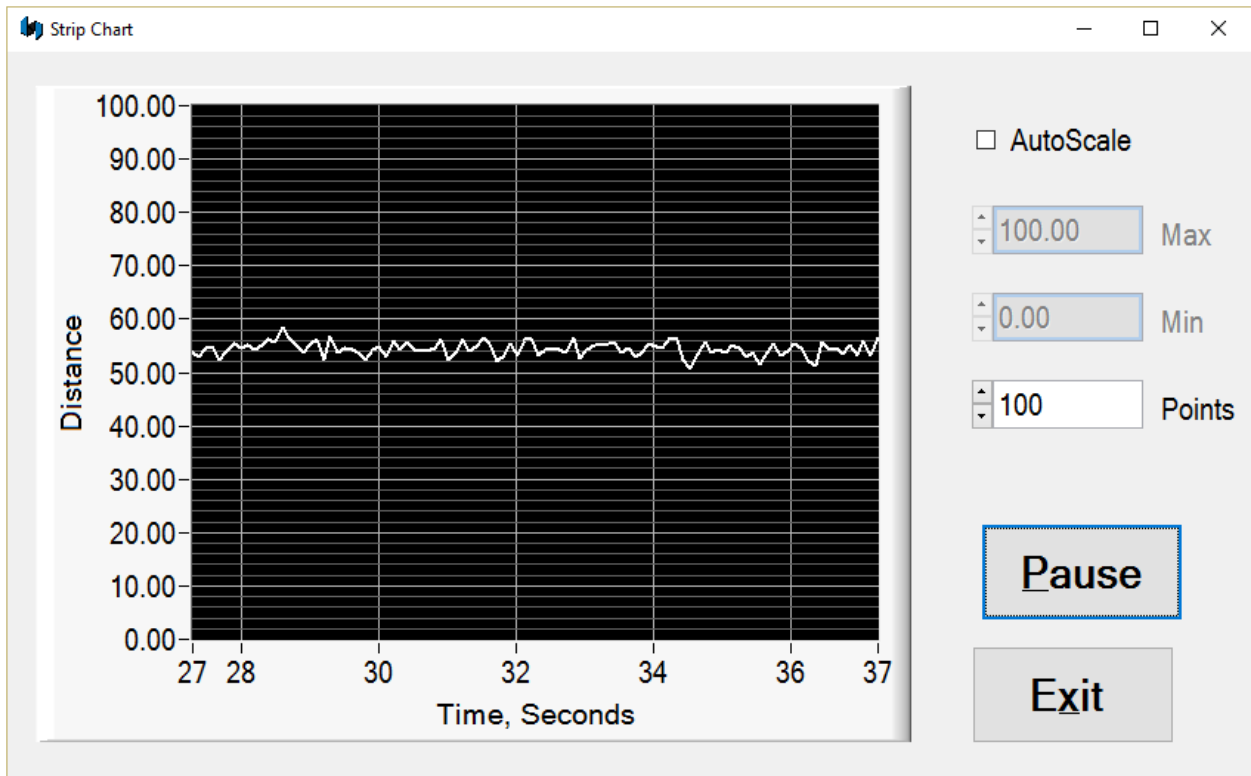


**Main GUI Screen**

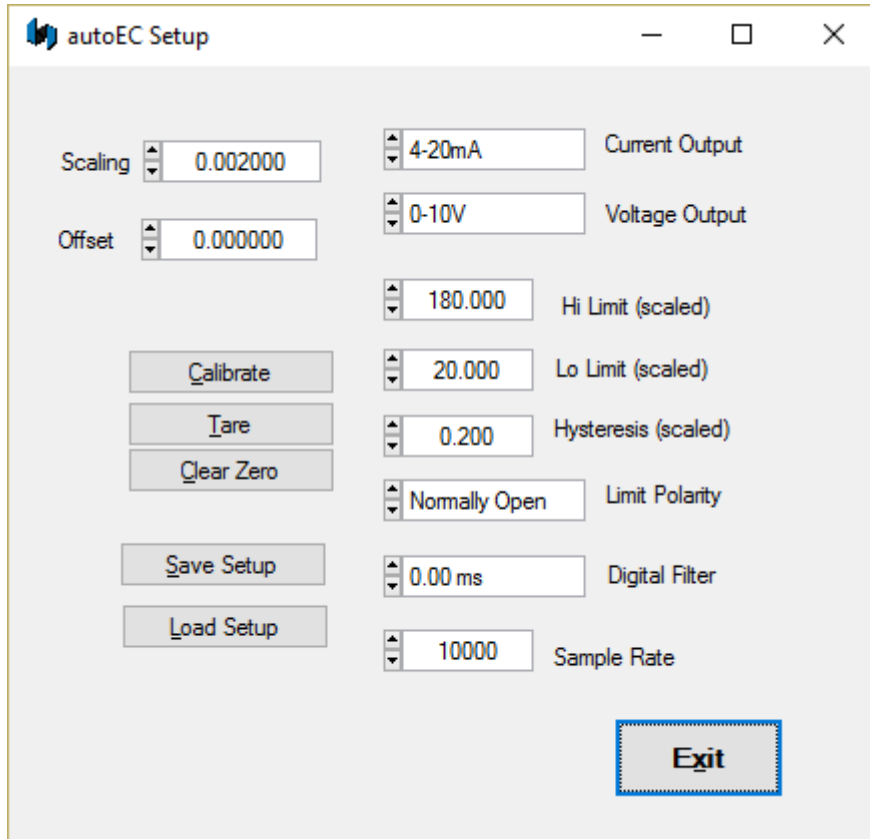
The GUI will start with the main screen as shown above. Note that it displays the unique serial number of the unit, the scaled distance output, and the relay state. There is also a strip chart function available by clicking on the 'Chart' button. You can also do fast sampling and FFT's (Fast Fourier Transforms) by clicking the 'FFT' button which is useful for machine analysis.

## Charting

You can use the charting function to monitor the outputs in stripchart form. In Windows the chart is updated every 0.1 seconds. You can change the vertical or horizontal ranges on the strip chart. You can also 'Pause' and look at data that has scrolled off of the screen.



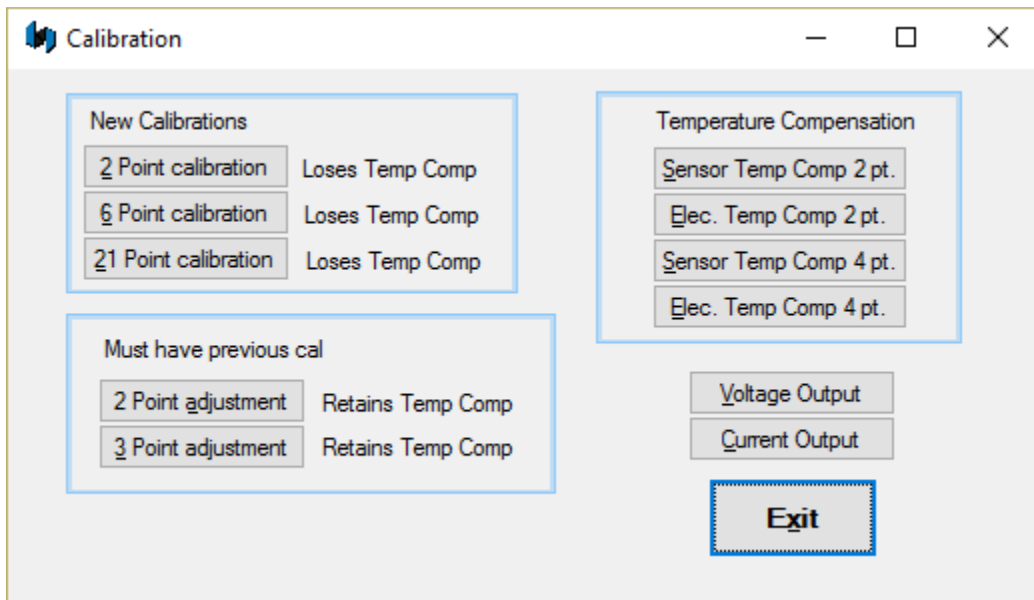
**StripChart**



**Setup Screen**

When you enter the setup screen most of the options are self explanatory. The scaling and the offset affects the digital reading from the device only and does not affect the DAC or current outputs from the autoEC. Note that if the scaling is 1 and the offset is zero the output displayed is scaled to be 0 to 100000 over the full range of the sensor calibration. If, for example, it was desired to display the output in percent of full range the scaling would be set to 0.001.

You can also 'Save Setup' to a file on your PC and 'Load Setup' later if you want to use different calibrations for the same sensor. You can still get pretty good performance even when over-ranging the sensor. This will save the entire setup and calibration to the file so you can go back to any exact configuration that was previously saved.

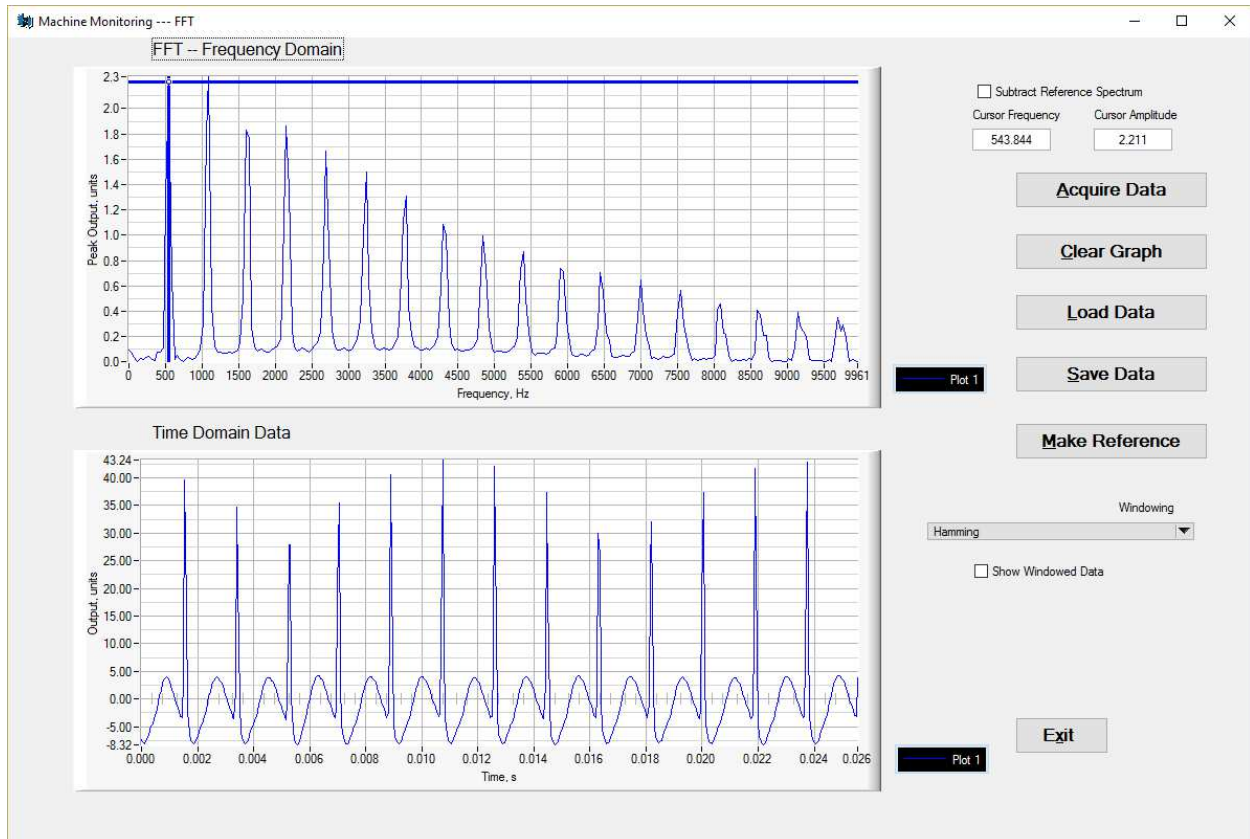


**Calibration Screen**

The calibration screen gives you all of the calibration options including the ability to calibrate the voltage and current outputs. Calibration is done simply by following the instructions on the prompts. Note that the calibration can only be as good as the device that it was calibrated with.

## FFT's and Machine Monitoring

The autoEC has the capability to collect 512 samples at the chosen sample rate, upload to the data to the PC, and do an FFT on the data. This can be useful for machine monitoring and complex analysis. In this particular screen shot a tool with a 0.6" diameter head was rotating at 30000 RPM on a shaft. There was a fiducial mark that is readily apparent on the time domain data (the lower graph). This is also responsible for some of the higher order harmonics as seen in the graph. You can also use the cursor to pinpoint the frequencies that are present and there amplitude.



**Fast Acquisition and FFT Screen**

### Acquire Data

Pressing this button will cause the autoEC to acquire 512 data points at the current sample rate. It subtracts off the mean and plots this data out on the time domain on the lower graph and in the frequency domain in the upper graph.

### Clear Graph

Clears the graph if desired.

### Load Data

Loads any previously saved data from a plot and re-computes the FFT.



### *Save Data*

Saves the time domain data from a given acquisition.

### *Make Reference*

Pressing the button will make the last acquisition the 'reference' and this data can be subtracted from any subsequent acquisitions if the 'Subtract Reference Spectrum' is checked. This only applies to the spectral data. The time domain data is unaffected.

### *Windowing*

This can be important to prevent 'spectral leakage'. This occurs if there is not an integer number of samples at a given frequency. This will essentially deemphasize both ends of the time domain data to minimize errors due to the spectral leakage. There are several methods to choose from including no window. The windowed data can be superimposed on the time domain data by checking the 'Show Windowed Data' which can be an aid in selecting the proper window for a given situation.

### *Zooming and Panning on Graphs*

You can use *zooming*—the ability to expand or contract the viewport around a particular point or area—in graph controls. When you zoom *in*, the logical area contained in the viewport gets smaller, showing the area with more resolution. When you zoom *out*, the viewport shows a wider area. You can also use *panning*, the ability to shift the viewport.

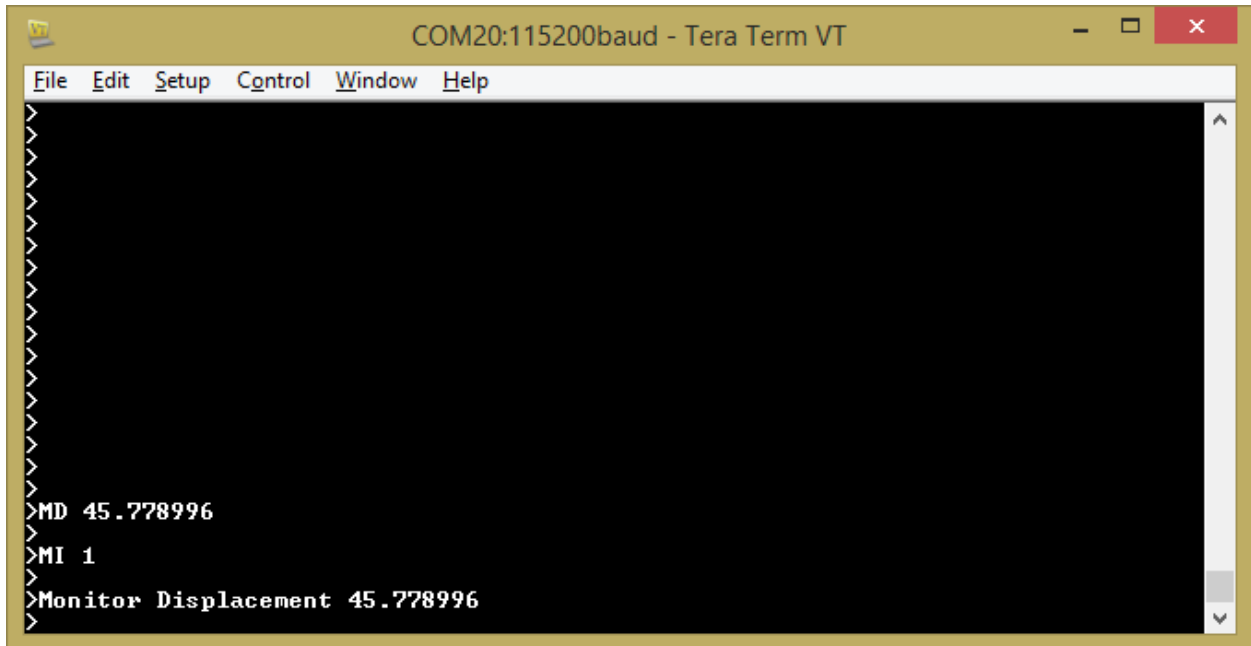
- You can define a rectangular zone that will become the new limits of the graph. To select these bounds, press <Ctrl> and click and hold the left mouse button to define the first corner of the box. Drag the mouse to define the opposite corner of the rectangle. When you are satisfied with the new boundaries of the graph, release the mouse button.
- To pan, press <Ctrl-Shift>, click and hold the left mouse button, and drag the mouse to new point. The graph viewport scrolls so that a new portion of the graph is visible. You can drag the mouse anywhere on the screen, even beyond the viewport. Panning is available whenever you enable zooming.
- To zoom out, press <Ctrl> and click and hold the right mouse button. You also can undo up to 25 of the most recent pans or zooms by pressing <Ctrl-Space> to reverse each successive change.

### *Changing the plot colors*

By right clicking on the legend you can change plot colors, names, line thickness, etc.

### ***Using a Terminal Program***

You can use any terminal program to execute simple commands from such as TeraTerm or HyperTerminal. The setting for this would be 115200 Baud, 8 bits, No Parity, and 1 Stop bit. Simply type in the commands as shown below. MD is Monitor Displacement for example. Lower case text is ignored so you can use full text with only the M and the D capitalized. TeraTerm is a freeware piece of software and is available for download at many sites.



**Figure 3 Terminal Software Example**

## CALIBRATION EXAMPLES

### *General Information*

There are some rules of thumb when using the autoEC:

- 1) The standard range is 1/3 the diameter of the sensor against a non-ferrous target, such as aluminum.
- 2) The offset (closest point to sensor face) should be set at 10% of the standard sensor range.
- 3) The range against non-magnetic targets can typically be extended to 150% of the standard range with reduced linearity and thermal sensitivity.
- 4) Magnetic targets will have a range about 20% of the diameter of the sensor but performance can vary significantly depending on the material and it's processing.
- 5) Larger sensor diameters (>35mm) are not as affected by the target material as smaller diameter sensors and will typically work better with the magnetic targets.
- 6) When using magnetic targets that are moving laterally to the sensor face (i.e. rotating targets) the temperature compensation option should not be used (regardless of sensor diameter). This is due to a 'generator effect' caused by fluctuations in permeability over the surface of the target influencing the temperature measurement of the sensor.
- 7) For most ranges, the 6 point calibration will typically yield good to very good results while the 21 point calibration will give excellent results.
- 8) When the calibrated range is less than 10% of the standard range a 2 point calibration will usually yield good results. At ranges less than 5% of the standard range, a 2 point calibration is recommended.
- 9) For calibrations via the USB interface, data can be taken in any order with the 'Done command' (**C2**, **C6**, **CD**, or **CAM** depending on the calibration type) issued when the calibration is complete.
- 10) Calibrations can be performed from MIN to MAX range or MAX to MIN range provided the calibration steps precede sequentially.
- 11) To save the calibration to EEPROM you must use the '**CS**' command.

## ***Calibration Fixturing***

A good calibration starts with good calibration fixturing and reference. While in some cases the autoEC can be calibrated in-situ, it is typically calibrated using fixturing specially made for the purpose. Small ranges may require special measuring equipment such as laser interferometers for the best accuracy.

## ***2 Point Linear Calibration***

Note: The 2 point calibration will zero out any temperature compensation done previously and will have to be redone.

- 1) Set the sensor flush with the target and move the micrometer to the MIN (offset) position. Zero the micrometer.
- 2) Position the micrometer at the desired MAX (full scale range + offset) position.
- 3) With the sensor at full scale, type USB command '**CF**'. You must wait for the unit to return from this command -- this can take approximately 20 seconds. The unit is optimizing the setup for the particular sensor, range, and target. Wait for this to finish.
- 4) Position the micrometer to the MIN position (offset). Type '**CZ**', then '**CP 0**' to take data.
- 5) Position the micrometer to the MAX position. Type '**CP 1**' to take data, then '**C2**' to complete the calibration.
- 6) Type '**CS**' to save the calibration to EEPROM.

The calibration is now complete. If the calibration is good, the autoEC will return a status of 0. A status of 1 is returned on a bad calibration and the calibration must be performed again.

## 6 Point Polynomial Calibration

Note: The 6 point calibration will zero out any temperature compensation done previously and will have to be redone.

Most of the procedure is the same as the 2 point calibration except with more data points. This calibration assumes the range is divided into 5 equal intervals. For example: a 0.5mm range will be divided into  $0.5/5 = 0.1\text{mm}$  intervals.

- 1) Set the sensor flush with the target and move the micrometer to the MIN (offset) position. Zero the micrometer.
- 2) Position the micrometer at the desired MAX (full scale range + offset) position.
- 3) With the sensor at full scale, type USB command '**CF**'. You must wait for the unit to return from this command -- this can take approximately 20 seconds. The unit is optimizing the setup for the particular sensor, range, and target. Wait for this to finish.
- 4) Position the micrometer to the MIN position. Type '**CZ**', then '**CP 0**' to take data.
- 5) Go to the 20% position (0.1mm in our example). Type '**CP 1**' to take data.
- 6) Repeat step 5 for 40%, 60%, and 80% positions. Type '**CP 2**', '**CP 3**', '**CP 4**' at these positions respectively.
- 7) Position the micrometer to the MAX position. Type '**CP 5**' to take data, then '**C6**' to complete the 6 point calibration.
- 8) Type '**CS**' to save the calibration to EEPROM.

The calibration is now complete. If the calibration is good, the autoEC will return a status of 0. A status of 1 is returned on a bad calibration and the calibration must be performed again.

## 21 Point Piecewise Calibration

Note: The 21 point calibration will zero out any temperature compensation done previously and will have to be redone.

Most of the procedure is the same as the 6 point calibration except with more data points. This procedure assumes the range is divided into 20 equal intervals. For example: a 0.5mm range is divided into  $0.5/20 = 0.025\text{mm}$  intervals.

- 1) Set the sensor flush with the target and move the micrometer to the MIN (offset) position. Zero the micrometer.
- 2) Position the micrometer at the desired MAX (full scale range + offset).
- 3) With the sensor at full scale, type USB command '**CF**'. You must wait for the unit to return from this command -- this can take approximately 20 seconds. The unit is optimizing the setup for the particular sensor, range, and target. Wait for this to finish.
- 4) Position the micrometer to the MIN (offset) position. Type '**CZ**', then '**CP 0**' to take data.
- 5) Go to the 5% (0.025mm in our example) position. Type '**CP 1**' to take data.
- 6) Repeat step 5 for 10-95% positions. Type '**CP 2**', '**CP 3**', '**CP 4**' ... '**CP19**' at these positions respectively.
- 7) Position the micrometer to the MAX position. Type '**CP 20**' to take data, then '**CD**' to complete the 21 point calibration.
- 8) Type '**CS**' to save the calibration to EEPROM.

The calibration is now complete. If the calibration is good, the autoEC will return a status of 0. A status of 1 is returned on a bad calibration and the calibration must be performed again.

## **2 Point Adjustment**

Note: The 2 point adjustment **will not** zero out any temperature compensation done previously and will have to be redone. The temperature compensation will remain intact.

- 1) Position the sensor at the MIN (offset) position and type '**CAZ**'.
- 2) Position the sensor at the MAX (full range + offset) position and type '**CAF**' to take data, then '**CAD**' to complete the adjustment.

The adjustment is now complete. If the calibration is good, the autoEC will return a status of 0. A status of 1 is returned on a bad adjustment. If the adjustment is not good, a full recalibration may be required.

## **3 Point Adjustment**

Note: The 2 point adjustment **will not** zero out any temperature compensation done previously and will have to be redone. The temperature compensation will remain intact.

- 1) Position the sensor at the MIN (offset) position and type '**CAZ**'.
- 2) Position the sensor at the MID (mid range or 50%) position and type '**CAM**'
- 3) Position the sensor at the MAX (full range + offset) position and type '**CAF**' to take data, then '**CAD**' to complete the adjustment.

The adjustment is now complete. If the calibration is good, the autoEC will return a status of 0. A status of 1 is returned on a bad adjustment. If the adjustment is not good, a full recalibration may be required.

## Temperature Compensation (Electronics and Sensor)

While the autoEC optimizes the sensor output for inherent temperature stability it can be improved further by temperature compensation. The temperature of the sensor is measured and used to compensate the output based on equations in the autoEC. Optionally the Electronics can also be temperature compensated separately from the sensors and uses a built in temperature sensor for the compensation. In either case the compensation method is the same. These equations are set by collecting data at 4 temperature points:

D1T1 -- Displacement 1, Temperature 1  
D1T2 -- Displacement 1, Temperature 2  
D2T1 -- Displacement 2, Temperature 1  
D2T2 -- Displacement 2, Temperature 2

The autoEC assumes that D1 is the same physical position for both T1 and T2. It does not assume that the temperature of D2T1 is the same as D1T1.

As with any calibration, temperature compensation depends on good fixturing. To some degree if the fixturing is moving in temperature (due to material coefficient of thermal expansion – CTE) the same way it does in the application, the autoEC will tend to compensate for it. In many cases the autoEC can be temperature compensated in-situ.

It is best to choose points D1 and D2 at 10% and 90% of the range (D1 could be 90% and D2 could be 10% -- does not matter). If the expected usage is in a narrower range, better results could be obtained in the important displacement band by calibrating over the narrower range.

1) The first point it expects to be at Displacement 1 Temperature 1 in a fixture. A good method is to fixture it at 90% of displacement (approximately -- it does not matter precisely) and the heat the sensor head (if cable is going to be in the hot environment it should also be included). If you are using the GUI you will see the relative Temp C x indicator rise as temperature increases and fall as it decreases. It works best to heat it up and then let it cool down just a bit before taking the first data point so that transient effects are not included. Typically if the sensor is heated until the relative C reads 10 or 12 or more that is sufficient. Let it cool down slightly to say 11 or even 9 and type '**CT 0**'.

2) Next go to Displacement 1 Temperature 2. Let it cool down until it is close to where it started though it is not necessary to let it cool down all the way. Then type '**CT 1**'.

3) Next go to Displacement 2 Temperature 1. Reposition the sensor in the fixturing to be at a second displacement. Typically 10% of the range is good setting. Again it is best to heat it up, let the transient go away and press the enter button at a relative C of 10 or 12. After the transient has gone away, type '**CT 2**'.

4) Next go to Displacement 2 Temperature 2. After the relative temperature goes down to near 1 or 2 press type '**CT 3**'. Type '**CT 4**' to complete this procedure if the compensation is for the sensor. Or, type '**CT 5**' to complete this procedure if the compensation is for the electronics.

5) Type '**CS**' to save the calibration to EEPROM.



A 0 is returned on a good and a 1 is returned on a bad temperature compensation. A full recalibration may be required on a bad calibration.

## OTHER FEATURES

### ***Limits & Relay***

The autoEC contains a solid state relay connected to pins 6 of the terminal block. The other pin of the relay is internally connected to ground. This relay has a 40 ohm closed impedance and is rated for 60V and 100mA. The relay is controlled by the limit settings and is set up as a window comparator. The hi and lo limits, polarity (NC or NO), and hysteresis are setup using the UDP commands. By default the relay will be on if the output is less than 10% or greater than 90% and off otherwise.

To set the limits and relay, the autoEC must be connected by a USB to a PC running console software.

The output from the system is from 0 to 100,000 where 100,000 is 100%. The relay is setup the same way.

For example, a command of SCLL 20000 sets the low limit to 20%.

S(R)CLP x	USER	X = polarity	Polarity	SET(READ) Limit Polarity 0 = NO 1= NC
S(R)CLH xxxx	USER	xx = Hi Limit	Hi Limit	SET(READ) Limit Hi (Signed Long Int)
S(R)CLL xxxxx	USER	xx = Lo Limit	Lo Limit	SET(READ) Limit LO (Signed Long Int)
S(R)CLD xxxx	USER	xx = Hysteresis	Hysteresis	SET(READ) Limit Deadband (Hysteresis) (Signed Long Int)

**Table 2 Relay Commands**

### ***IO bit/AUTOZERO***

The IO bit (pin 4) is set up to have the same functionality as zeroing the system from the console or the front panel menu. The system will zero the output when pin 4 is grounded and will function normally when it is open. This means if the system is setup for bipolar voltages it will go to 50% when grounded and 0% for unipolar voltage settings.

Note: this does not move the effective range of the system as it is only offsetting the output reading. If the sensor is physically at 5% of the range and is zeroed, the bipolar output setting the output will read 50% but then the linear range will then be 45% to 145%.

## APPENDIX A: COMMAND LIST

The following are the low level commands for the user to program an interface. Many of the setup commands are read or write. The command starts with an 'S' for a write (such as SCLL 20000) or an 'R' for a read (RCLL will read back the setting). Settings are stored in non-volatile system memory.

Command	Passlevel Required	Parameters	Returns	Comments
<b>Monitor Commands</b>				
MD	NONE	NONE	Distance Output	Monitor Distance Output 100000=100%
ML	NONE	NONE	Monitor Limit	Monitor Limit 0= in range 1=low 2 = hi
MR	NONE	NONE	Monitor Relay	Monitor Relay 0= Open 1 = Closed
<b>AutoZero Function</b>				
ZZ	NONE	NONE	--	Zeroes the output
ZC	NONE	NONE	--	Clears the zero on the output
<b>Limit Setup</b>				
S(R)CLP x	USER	X = polarity	Polarity	SET(READ) Limit Polarity 0 = NO 1= NC
S(R)CLH xxxx	USER	xx = Hi Limit	Hi Limit	SET(READ) Limit Hi (Signed Long Int)
S(R)CLL xxxxx	USER	xx = Lo Limit	Lo Limit	SET(READ) Limit LO (Signed Long Int)
S(R)CLD xxxx	USER	xx = Hysteresis	Hysteresis	SET(READ) Limit Deadband (Hysteresis) (Signed Long Int)
<b>Output Setup</b>				
S(R)UI x	USER	x = setting	Setting	SET(READ) User Current Output 0=0-20mA 1=4-20mA
S(R)UV x	USER	x = setting	Setting	SET(READ) User Voltage output 0=0-5V 1 =+/-5V 2=0-10V 3=+/-10V
S(R)UF x	USER	x = setting	Setting	Digital Filter (0-8) 0= no filter 'tau' = $\tau = (1/2^x) * (1/\text{sample rate})$
S(R)UR x	USER	x = setting	Setting	Sample Rate (1-22500)

Command	Passlevel Required	Parameters	Returns	Comments
<b>System</b>				
RXR	NONE	NONE	Revision	Read Firmware Revision
U	NONE	Sets Passlevel	Passlevel 0-2	Unlocks for higher level control U EDI<ret> -- unlocks to User Level U<ret> -- sets password to normal level
<b>MISC TIMER</b>				
WC	NONE	NONE	Seconds	Watch Clock (seconds since power on)
WT	NONE	NONE	Ticks	Watch Ticks (Ticks since power on)
<b>CALIBRATION</b>				
CS	NONE	NONE	--	Saves the calibration and all parameters
CF	NONE	NONE	Frequency	Set Optimal Full Scale – Sets Frequency and Optimal Coil Current – sensor must be positioned at max displacement from sensor. This is the first thing done in a calibration.
CZ	NONE	NONE	--	Sets Zero and sets gains and offsets (Executed after CF) – sensor must be positioned at the minimum displacement from sensor. This is the second thing done in a calibration
CP x	NONE	X = 0-20	AD Reading	Cal Point (0-20) for piecewise linearization – sensor must be positioned at the correct percent of full scale – i.e. 0=0%, 1=5%,2 =10% ... 20=100% - - direction (min to max or max to min) does not matter as long as it changes monotonically. For 6 point polynomial cals only use 0-5 points and they must be spaced 20% apart ... i.e. pt 0 is 20%, pt1 is 40% ... pt 5 = 100% of range. For a 2 point cal pt 0 = 0% pt 1 = 100%.
CD	NONE	NONE	Status	Completes the 21 point calibration and sets up the tables for operation
C6	NONE	NONE	Status	Completes the 6 point polynomial cal
C2	NONE	NONE	Status	Completes the 2 point linear cal
CAZ	NONE	NONE	--	Cal Adjust zero point
CAM	NONE	NONE	--	Cal Adjust mid point
CAF	NONE	NONE	--	Cal Adjust full scale point
CAD	NONE	NONE	Status	Complete 2 Point Adjust
CT 0	NONE	NONE	--	Collect Temp Comp Data for D1T1
CT 1	NONE	NONE	--	Collect Temp Comp Data for D1T2
CT 2	NONE	NONE	--	Collect Temp Comp Data for D2T1
CT 3	NONE	NONE	--	Collect Temp Comp Data for D2T2
CT 4	NONE	NONE	Status	Completes Temperature Compensation for Sensor
CT 5	NONE	NONE	Status	Completes Temperature Compensation for Electronics

## SENSORS

The autoEC will work with many off the shelf sensors from various manufacturers. It is fairly easy to make your own custom sensor that will work with the autoEC. The rule of thumb for the sensors to work best is for the inductance to be between 10 micro-Henrys and 50 micro-Henrys and the DC resistance to be 1-10 ohms, though values outside of that range may work as well.

Performance is based on a couple of things. Generally higher Q sensors will work better but the main factor is the diameter of the sensor coil itself. The performance will vary depending on the material with performance best against an aluminum target. The general rules of thumb for performance is are follows:

### ***Typical Performance with non-magnetic conductive targets:***

Offset	10% of coil diameter
Short range	5-10% of coil diameter
Nominal range	30-35% of coil diameter
Long range	50% of coil diameter
Specifications for aluminum target, 2 meter cable lengths, nominal range	
Non-linearity 6 pt. calibration	< +/-0.3% Full scale range
Non-linearity 21 pt. calibration	< +/-0.1% Full scale range
Static Resolution	<0.001% Full scale range RMS
Resolution @100Hz	<0.01% Full scale range RMS
Resolution @1000Hz	<0.02% Full scale range RMS
Thermal Sensitivity	0.05 %FR/°F (0.1%FS/°C)
Thermal Sensitivity(with active Temp Comp)	0.01 %FR/°F (0.02%FS/°C)

### **Typical Performance with Aluminum, 2 m Cable**

\* note: it is possible to use the sensors outside of the short, nominal, or long ranges but for the purpose of characterizing typical performance these definitions are made.

### ***Sensor With Ferrite Cores***

The autoEC can work just fine with sensors that have ferrite cores, however, they will typically have a much greater temperature coefficient due to the ferrite and can be sensitive to magnetic fields. The autoEC has been tried with sensors as high as 168uH.

## ***Typical Performance with magnetic targets***

When using magnetic targets it is much more difficult to generalize the performance as there is a dependency on the permeability of the target that is difficult to characterize. For sensors 16mm in diameter and larger, however, performance is generally similar to performance with non-magnetic targets. For sensors <12mm the range must be reduced significantly, by at least 50% or more and in some cases it may not work at all. Temperature dependencies can also be very high. The performance with magnetic targets really needs to be evaluated on a case by case basis.

### **General Rules when using autoEC with magnetic target materials:**

1. On medium sized sensors (~12mm in diameter) standard range is reduced to 65-75% of the standard range compared to an aluminum target.
2. Non-linearity is somewhat degraded. A 21 point calibration is recommended for better non-linearity with longer ranges.
3. The larger the sensor diameter, the less performance is degraded compared to aluminum.
4. Long cable lengths are not recommended for good performance.
5. Temperature compensation is recommended for best temperature performance.
6. Temperature compensation should be done with the cable in the same environment expected during use. The sensor cable can account for significant shifts with temperature changes.
7. Targets rotating or moving at right angles to the sensor face can cause the temperature compensation to add significant noise to the output signal (i.e. degraded resolution). This is due to slight changes in magnetism of the target material.
8. Temperature compensation on smaller sensors will cause the system to exhibit high transients on fast thermal changes.

## APPENDIX C: autoEC TYPICAL SPECIFICATIONS

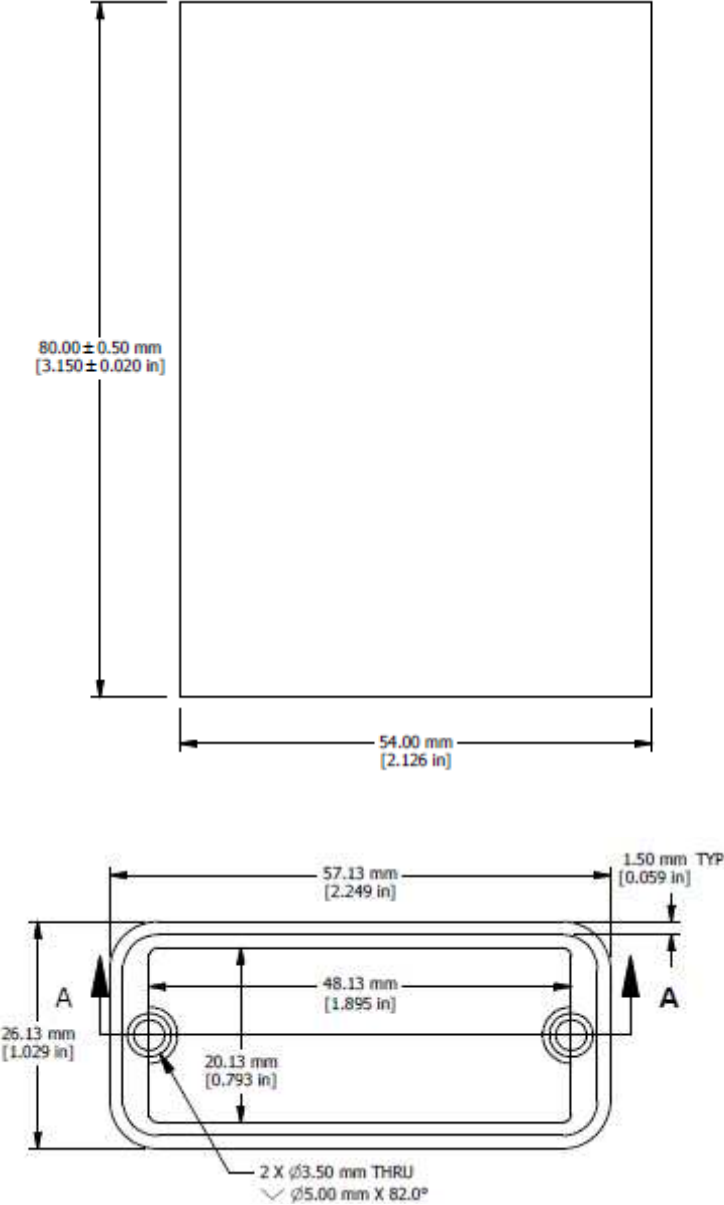
Specifications below are typical, but are sensor and target dependent. Some magnetic targets may not work well with the autoEC.

Parameter	Specification	Notes
Power Supply	+4.5-5.5V	Current will change with input
Input Current	470mA	At +5V input typical
Voltage Output	0-5V, +/-5V, 0-10V, +/-10V	Voltage and current are simultaneously output, Outputs will over/under range by 1%
Current Output	0-20mA, 4-20mA	250 ohm max load
Range	33% of sensor diameter standard	Ranges can vary typically from 5% of the standard range to 150% of standard range on non-magnetic targets. Magnetic targets are highly variable.
Offset	10% of range	
Resolution	1/3000 RMS at full bandwidth no filtering	Typical
Resolution Static	1/100000 RMS	Typical
Linearity 6 pt. Cal	0.3% of Full Range	Least Squares over standard range typical
Linearity 21 pt. Cal	0.1% of Full Range	Least Squares over standard range typical
Targets	Any conductive	Some magnetic targets may not work well or only over a substantially reduced range
Temp Co w/o temp comp	0.1%FR/°C	Standard range/AL target Typical sensor head only -- no cable
TempCo w/Temp comp	0.02%FR/°C	Standard range/AL target
Electronics TempCo	0.05-0.1%/°C	Standard range/AL target Typical with Electronics Temp Comp 5x typical improvement
Electronics Temp Range	0-60 °C	
Sensor DC Resistance	0.5 to 20 ohms	<0.5 ohms is 'bad sensor', >20 is 'no sensor'
Sensor Inductance	10uH to 100uH	Tested with sensors in this range. May be functional with sensors up to 10mH; function not guaranteed.
Max USB Cable Length	2 meters	In some cases it may work at longer lengths.

### Specifications Subject to Change without Notice

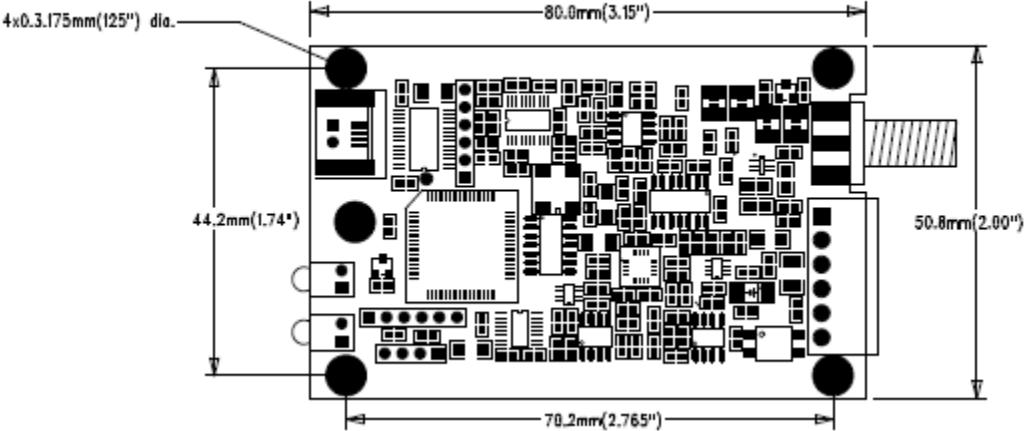
# APPENDIX E: DIMENSIONS

Dimensions in mm (in).





**OEM Version: PCB Only**



## APPENDIX G: DIGITAL FILTER

The autoEC (version 2 and higher) can sample up to 22,500 samples per second. Previous versions have sample rates of 5,000 and 10,000 sps only. The autoEC obviously has analog filtering on the front end but also has the ability to digitally filter the data. The digital filter was designed with a very efficient, simple algorithm:

$$\text{Output} = \text{Input} (1/2^n) + O_{.1}(1-1/2^n)$$

where:

**Output = the output of the system (before linearization)**

**Input = ADC output for a given sample**

**n = the integer value of the filter**

**O<sub>.1</sub> = previous sampled value of the filter output**

It can be seen that if n is = 2, 25% of the current AD value is summed with 75% of the previous output from the filter. This filter time constant is approximately (2<sup>n</sup>/sample rate). For a sample rate of 5,000 samples per second and n = 3, the time constant (τ) will be approximately (2<sup>3</sup>/5000) or 0.0016 seconds (1.6 milliseconds). The rise time is measured traditionally from 10% to 90% of the final value is approximately 2.2 \* the time constant (τ) or 3.52ms. The bandwidth is related to the rise time (tr) by f<sub>3dB</sub> × tr = 0.35 for this simple case. In this case the bandwidth (-3dB) is approximately: f<sub>3dB</sub> = 0.35/0.00352 ~ 100 Hz. In the autoEC display for filter selection, the display shows the value of

$$\text{'tau'} = \tau = (1/2^n) \times (1/\text{sample rate})$$

For speed reasons, only integer values of n are allowed, so selection of the time constant values are limited. The following tables show values of time constants for the sample rate selections. Note that factory default setting is 10,000 samples per second.

5 kHz	time constant	rise time	bandwidth
n	τ,s	t <sub>r</sub> ,s	f <sub>-3dB</sub> ,Hz
0	NA	NA	NA
1	0.0004	0.00088	397.7273
2	0.0008	0.00176	198.8636
3	0.0016	0.00352	99.43182
4	0.0032	0.00704	49.71591
5	0.0064	0.01408	24.85795
6	0.0128	0.02816	12.42898
7	0.0256	0.05632	6.214489
8	0.0512	0.11264	3.107244

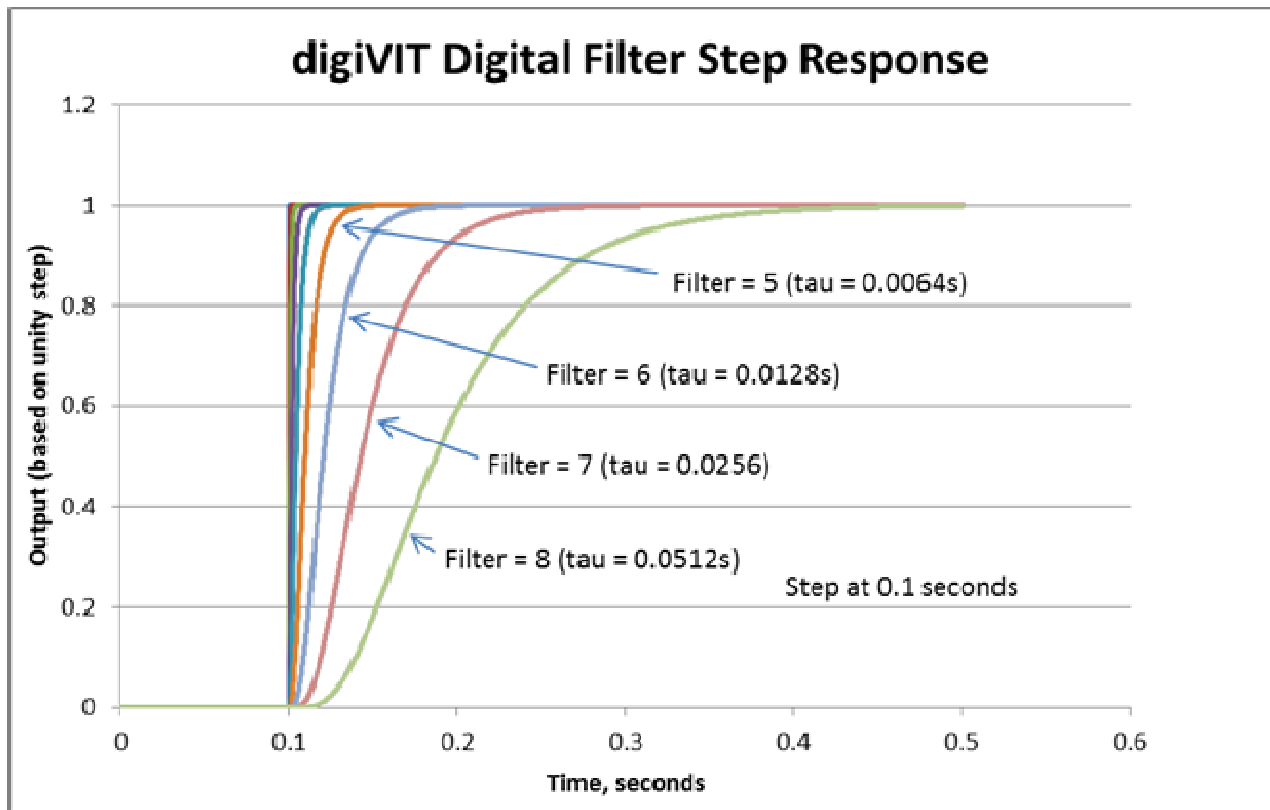
10 kHz	time constant	rise time	bandwidth
--------	---------------	-----------	-----------

n	$\tau, s$	$t_r, s$	$f_{-3dB}, Hz$
0	NA	NA	NA
1	0.0002	0.00044	795.4545
2	0.0004	0.00088	397.7273
3	0.0008	0.00176	198.8636
4	0.0016	0.00352	99.43182
5	0.0032	0.00704	49.71591
6	0.0064	0.01408	24.85795
7	0.0128	0.02816	12.42898
8	0.0256	0.05632	6.214489

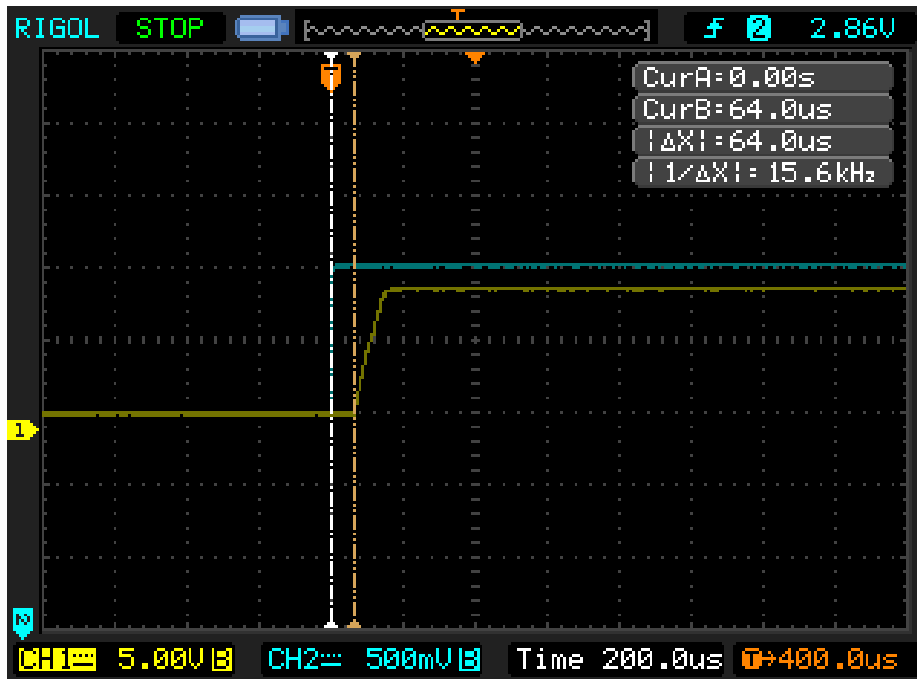
20 kHz	time constant	rise time	bandwidth
n	$\tau, s$	$t_r, s$	$f_{-3dB}, Hz$
0	NA	NA	NA
1	0.0001	0.00022	1590.909
2	0.0002	0.00044	795.4545
3	0.0004	0.00088	397.7273
4	0.0008	0.00176	198.8636
5	0.0016	0.00352	99.43182
6	0.0032	0.00704	49.71591
7	0.0064	0.01408	24.85795
8	0.0128	0.02816	12.42898

22.5 kHz	time constant	rise time	bandwidth
n	$\tau, s$	$t_r, s$	$f_{-3dB}, Hz$
0	NA	NA	NA
1	0.0001	0.0002	1750
2	0.0002	0.0004	875
3	0.0004	0.0008	437.5
4	0.0007	0.0016	218.75
5	0.0015	0.0032	109.375
6	0.0029	0.0064	54.6875
7	0.0058	0.0128	27.34375
8	0.0116	0.0256	13.67188

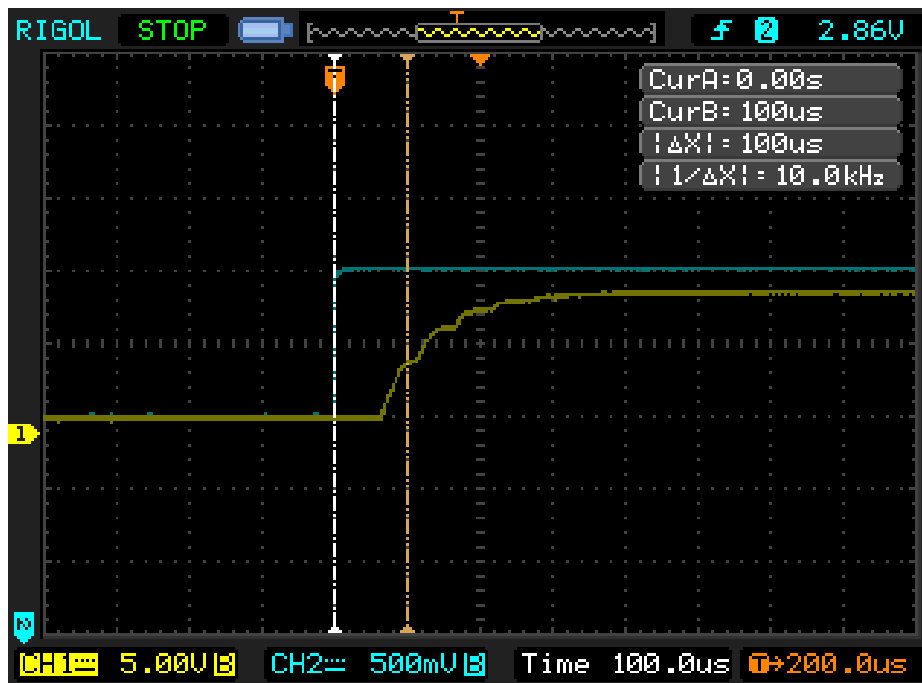
The Time Constants are based on the frequency. Note that for a step input, 1 time constant later the output will be at 63% of the final value. At 3 time constants, the output will be at 95% of the final value. This is illustrated in the table below.



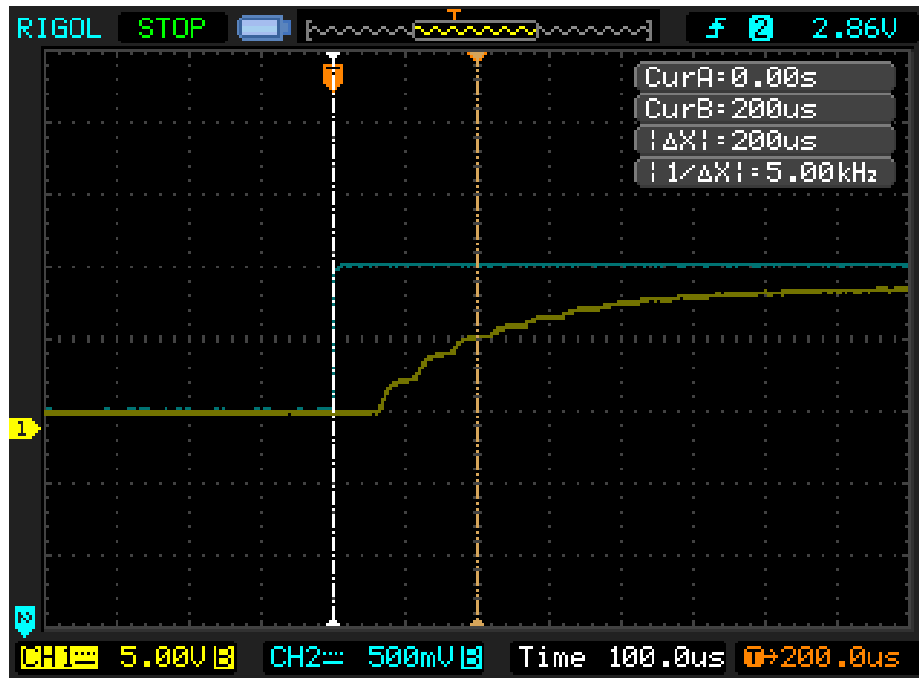
The following oscilloscope screen captures show the real delay and the effect of the filtering on a step input with the sample rate set to 20 kHz:



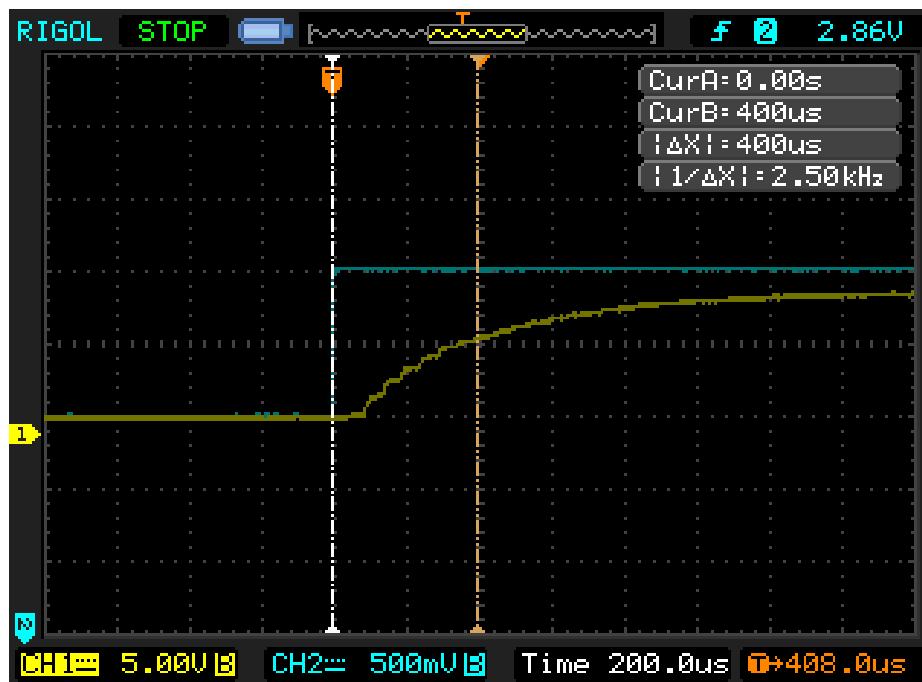
n=-0



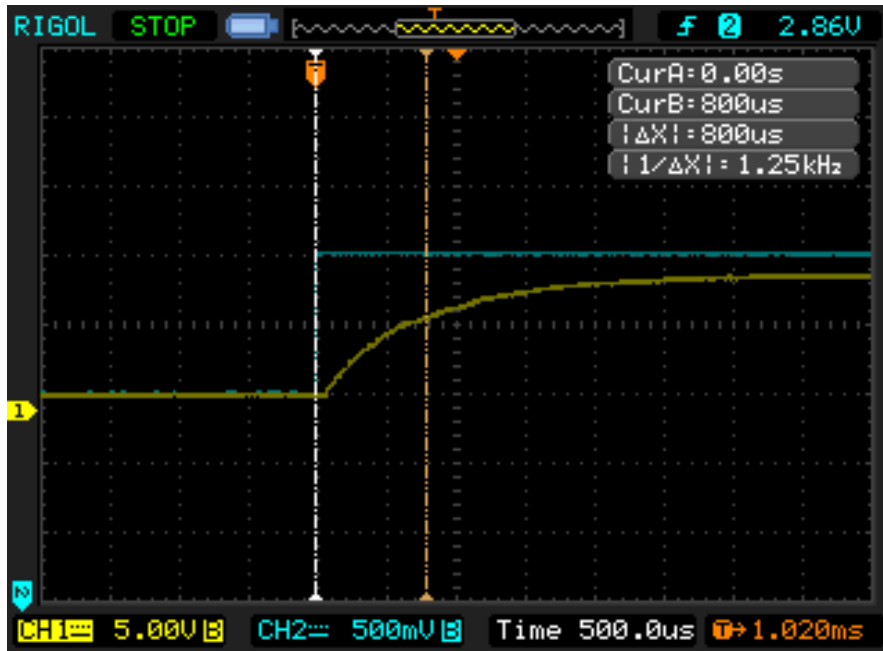
n=1,  $\tau = 100$  microseconds



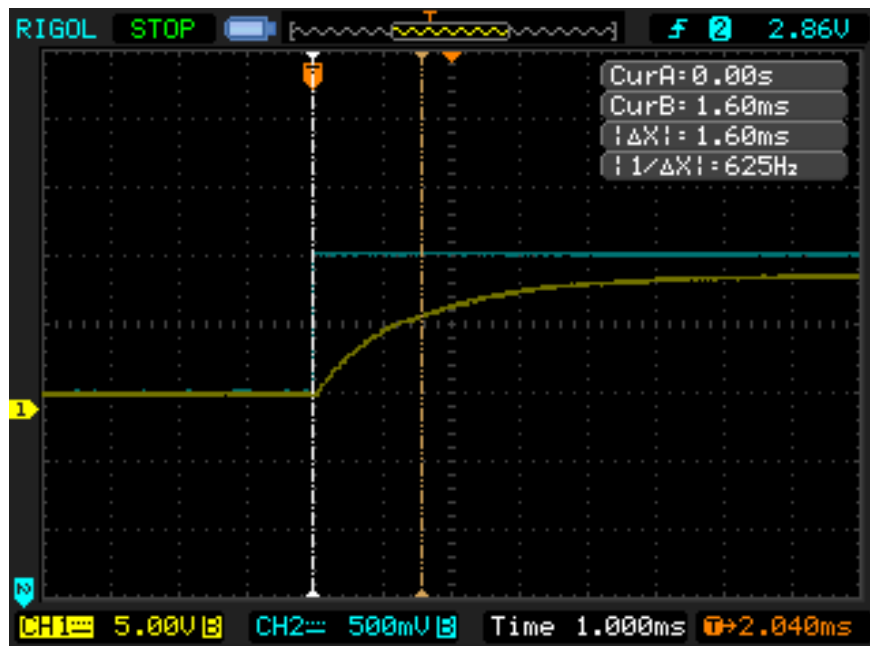
$n=2$ ,  $\tau = 200$  microseconds



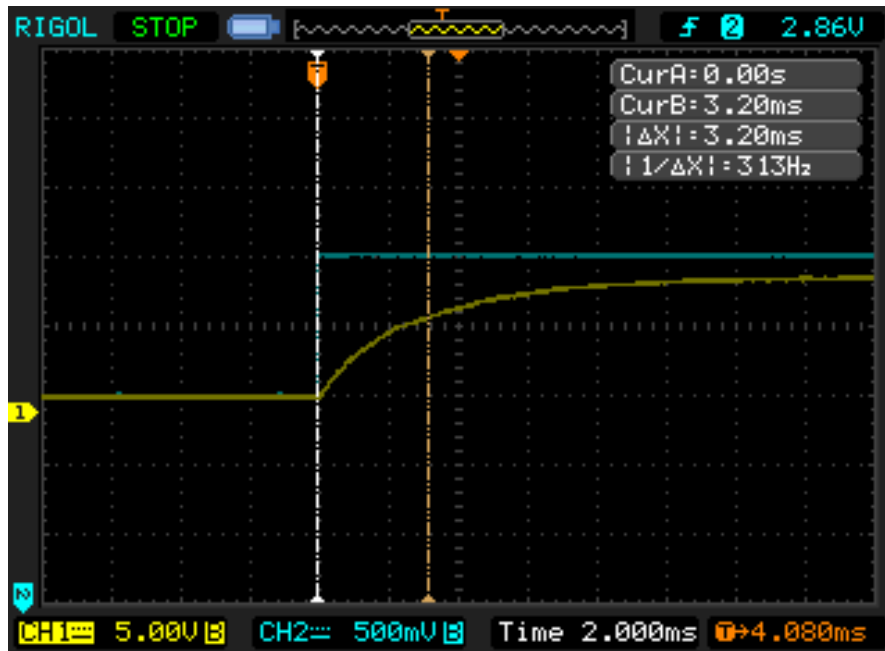
$n=3$ ,  $\tau = 400$  microseconds



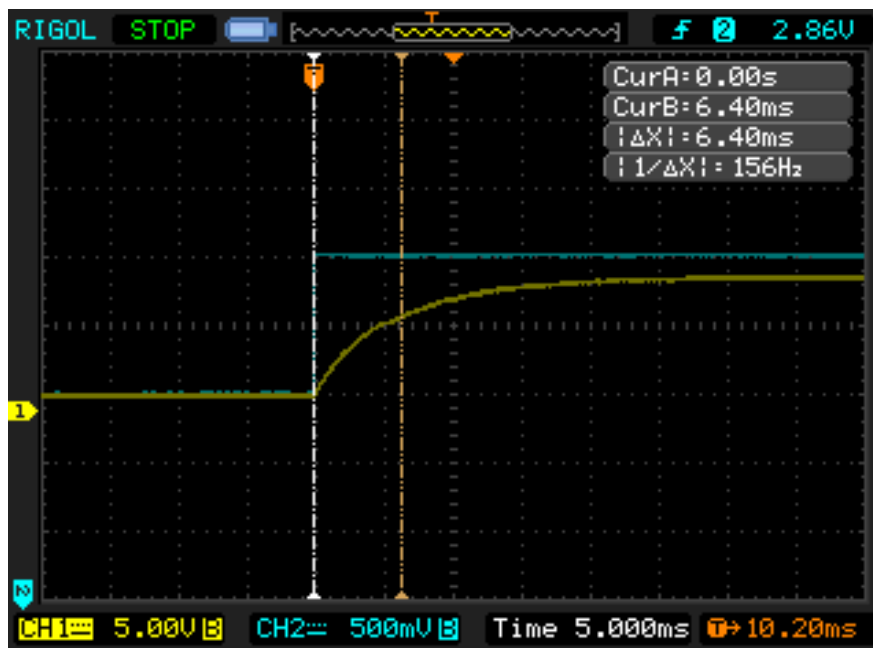
$n=4, \tau = 800$  microseconds



$n=5, \tau = 1.6$  milliseconds

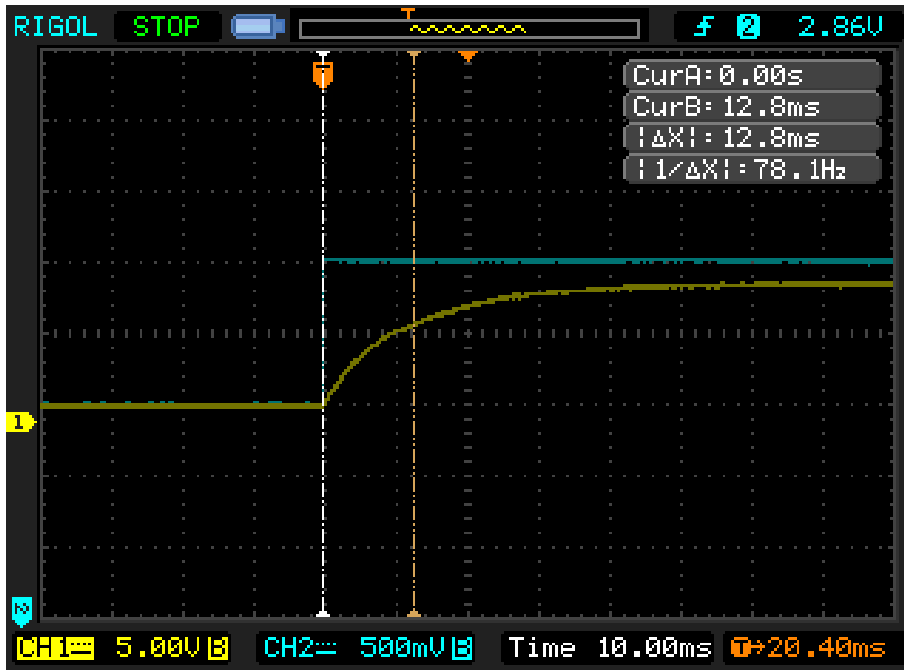


$n=6, \tau = 3.2$  milliseconds



$n=7, \tau = 6.4$  milliseconds





$n=8, \tau = 12.8$  milliseconds

## APPENDIX H: SOFTWARE LICENSE AGREEMENT

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## Warranty

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