digiVIT

Non-contact Displacement Measuring System User's Manual

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PART 1 – INTRODUCTION

The Kaman digiVIT is a revolutionary inductive displacement measuring instrument. The digiVIT simplifies use of a variety of Eddy Current sensors for precision measurements of; displacement, position, vibration, run-out, etc, in typical and difficult applications. The digiVIT is user configurable and adjustable.

The digiVIT does not require any special factory setup to work with most inductive sensors. It incorporates a self tuning mechanism that optimizes set up for a given sensor, cable length, conductive target material, and range. Using the front panel controls, the digiVIT can easily be calibrated, temperature compensated, and adjusted for a variety of voltage and current output options.

Getting Started

1.1 Connect Power
A +24 VDC power supply capable of supplying 0.13A is required to power digiVIT. Connect the power supply to the digiVIT terminal block pins 1 and 2 (reference PART 2 of this manual on connections).

1.2 Connect the Sensor
The sensor is connected to the SMA connector. On application of power, if no sensor is connected or the digiVIT senses an open connection, the message 'No Sensor' will appear on the display. If, the sensor is defective or its resistance is too low, the message 'Bad Sensor' will be displayed. If the unit was previously calibrated, the display may indicate a voltage, current or percentage depending on how the display was configured. If voltage or current was not selected, the default display is percent of full scale.

1.3 Calibrate the Sensor
If factory calibration has not been performed, the sensor must be calibrated before it will function properly. Reference PART 6 of this manual for calibration examples.

1.4 Connect the Outputs
Connect either the analog voltage output, current output, or use the Ethernet port over a UDP interface. For the analog voltage and current output, output ranges (i.e. 0-5V, ±5V, 0-10V, ±10V, 0-20mA, or 4-20mA) can be selected using the front panel menu.

For fixturing of sensors and other application considerations, reference Kaman's Inductive Technology Handbook. A copy can be downloaded free of charge from Kaman's website: www.kamansensors.com.

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PART 2 – CONNECTIONS

The digiVIT I/O connections are all through a 10 pin removable terminal block. The DigiVIT sensor is connected through an SMA coaxial connector on the opposite side of the enclosure. An RJ45 Ethernet connection is provided for UDP/IP communication.

Pin	Name	Function
1	+24V	+24V Input @ 0.13A (must accommodate power-on surge current up to 300mA)
2	Gnd	Ground
3	Vout	Voltage Output (0-5, ±5, 0-10, ±10)
4	Gnd	Ground
5	Iout	Curent Loop Output (0-20mA, 4-20mA)
6	Gnd	Ground
7	NC	No Connection
8	IO	IO Bit for special functions -- standard setup for Autozero when grounded.
9	Relay	Solid State Relay Connection
10	Relay	Solid State Relay Connection

Table 1 Terminal Block Pin-Out

PART 3 - FRONT PANEL CONTROLS

The digiVIT can easily be set up using the front panel controls.

1. Sensor connection (SMA)
2. Digital display
3. Scroll up pushbutton
4. Scroll down pushbutton
5. Escape pushbutton
6. Enter pushbutton
7. Ethernet connection (RJ45)
8. I/O screw terminals

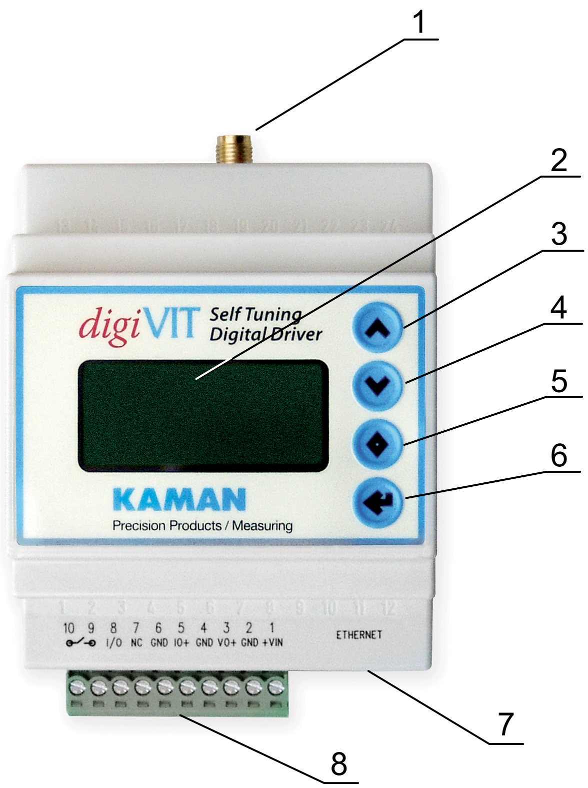

Figure 1 Front Panel Controls

Notes:

1) Press the Escape pushbutton (#5 in the figure above) momentarily to return to the previous menu tree branch.

2) Press and hold the Escape pushbutton to return to the normal run mode.

3) Press and hold the Up pushbutton (#3 in the figure above) on power on to restore the digiVIT to factory settings. This will erase any saved calibration and digiVIT must be re-calibrated prior to use.

PART 4 – MENU TREE

The menu tree for digiVIT, accessed by pushing either the Scroll Up or Scroll Down pushbuttons on the front panel, is shown below. The Scroll Up and Scroll Down pushbuttons will cycle through the options in a particular branch. To access a submenu simply scroll up or down in the main menu until the desired submenu is displayed, then push the Enter pushbutton. To leave a submenu, momentarily push the Escape pushbutton. To return to the normal run mode, depress and hold the Escape pushbutton.

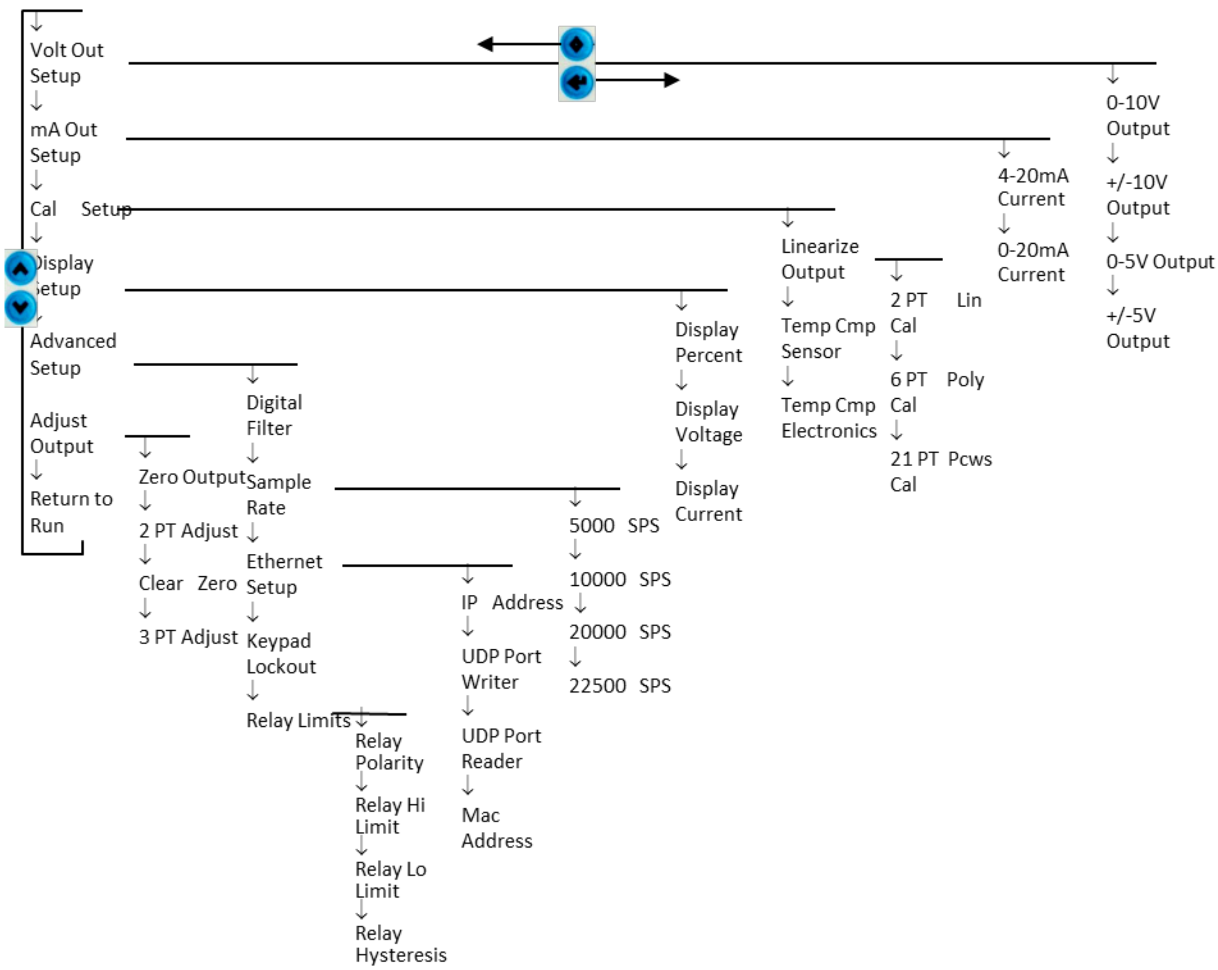

Figure 2 Menu Tree

4.1 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.

4.2 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.

4.3 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.

4.4 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.

4.4.1 2 Pt. Cal

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.

<u>Note: Any previous temperature compensation calibration will be voided when a 2 Pt. calibration is performed.</u>

4.4.2 6 Pt. Poly Cal

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.

Note: Any previous temperature compensation calibration will be voided when a 6 Pt. calibration is performed.

4.4.3 21 Pt. Pcws Cal

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%.

Note: Any previous temperature compensation calibration will be voided when a 21 Pt. calibration is performed.

4.5 Temperature Compensation

The digiVIT 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 aproximately10% 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 (see section 4.8.2 or 4.8.4). Temperature coefficients are not affected by a 2 point or 3 point adjustment calibration.

4.6 Display Setup

The display has several different output options:

4.6.1 Display Percent

Displays the percentage of the calibrated range where the sensor is positioned. Over and under range will show greater than 100% and less than 0% but the voltage outputs will be constrained to -1% to +101%. Current outputs are constrained to -5% to +105% (but will not go below 0mA).

4.6.2 Display Voltage

Displays the selected voltage output.

4.6.3 Display Current

Displays the selected current output.

4.7 Advanced Setup

4.7.1 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.

4.7.2 Sample Rate

The sample rate of the system can be selected from; 5,000, 10,000, 20,000, or 22,500 samples per second. 10,000 samples per second is the default. Higher sample rates can be selected for special applications when required.

Note that 20,000 and 22,500 samples per second are only available in digiVITs with software versions 1.51 and higher. The software version is displayed upon power up of the digiVIT.

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

At 10,000 samples per second and lower, both analog voltage and current are output simultaneously. At 20,000 samples per second and higher, either analog voltage or current is output, but not both. Analog current is output if current is shown in the display. Analog voltage is output if either voltage or percent is shown in the display.

4.7.3 Ethernet Setup

The Ethernet setup allows change of the IP Address and the UDP reader and writer ports for connection to the unit.

4.7.4 Keypad Lockout

To prevent unauthorized access, the keypad can be disabled. When the keypad is locked out none of the buttons on the front panel are active. To reactive the keypad press and hold the diamond and up arrow buttons until the menu reappears.

4.8 Adjust Output

4.8.1 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.

4.8.2 2 Pt. Adjust

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.

4.8.3 Clear Zero

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

4.8.4 3 Pt. Adjust

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.

PART 5 - ETHERNET OUTPUT

The digiVIT has an Ethernet output that communicates via a UDP/IP protocol. To protect the packet it is required that any command is preceded by a sequence number and has a checksum at the end. It has a fixed IP address (which can be changed) and utilizes fixed ports (these can also be changed) for sending and receiving data.

Default IP Address & Ports

Default IP Address: 192.168.0.145
Default UDP Writer Port: 55555
Default UDP Reader Port: 55556

5.2 UDP Packet

The packet sent over the UDP port must be preceded by a sequence number and followed by a checksum. This is necessary because UDP does not guarantee arrival of the packet to the host. The format of the packet is:

$*s*<Payload>#CC

Where the $ is the command preface and s is a sequence character from ASCII 'a' to 'z'. When the digiVIT receives a command, it will respond with the same sequence number sent as the first character of the string. It is up to the host to determine if the packet arrived in sequence and to take any action.

The checksum is the last two characters and is preceded by the # sign indicating the checksum characters follow as the payload length is variable. It is the inverted 8 bit sum of the ASCII values in the payload including the sequence number.

5.3 Console Software

Console software that lets the user enter UDP commands directly is available from Kaman's website: www.kamansensors.com. Examples for LabWindows and Labview programs are also available. Other software that allows more extensive features is also available from Kaman. Contact a Kaman representative for more information.

The console connects directly to a PC Ethernet port (typically the second Ethernet wireless connection may have to be disabled as it may attempt to use it). It can also be connected to a hub or switch or the PC wireless port if configured. It is a simple way of executing the UDP commands.

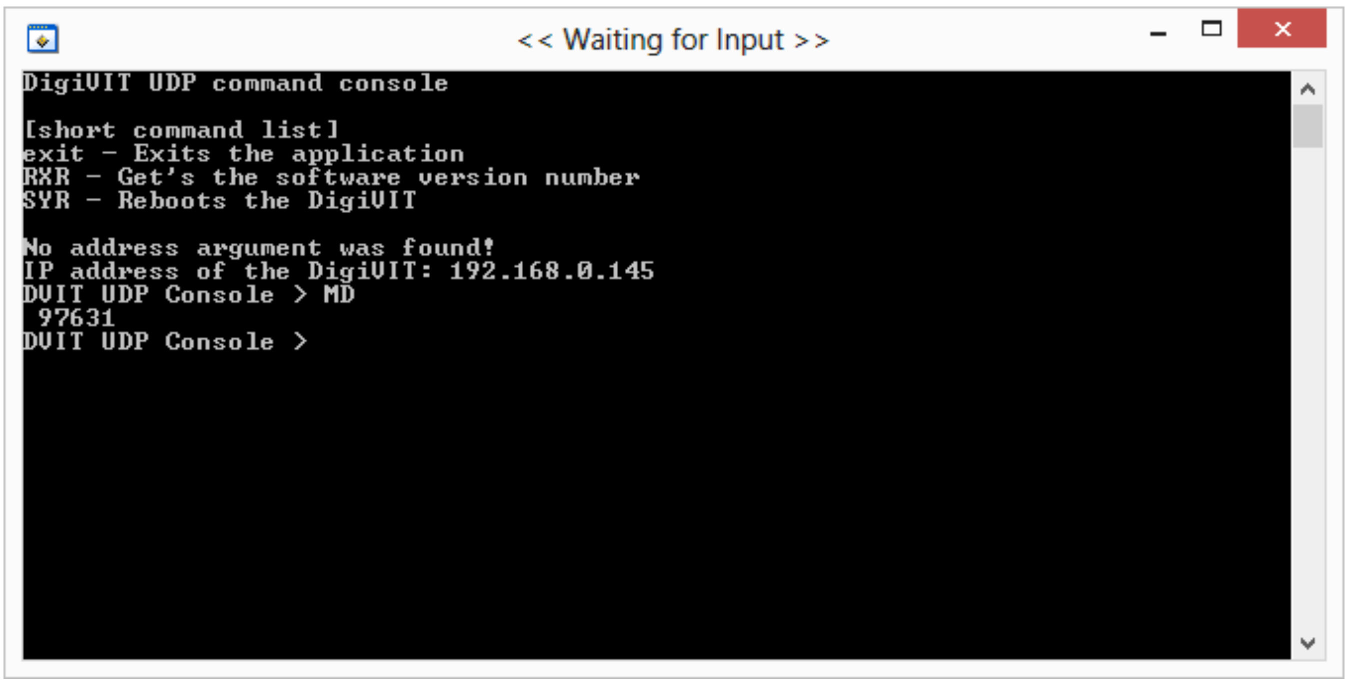

Figure 3 Command Console Software Example

PART 6 - CALIBRATION EXAMPLES

6.1 General Information

There are some rules of thumb when using the digiVIT:

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) All calibrations can be performed through the front panel or via a UDP command over the Ethernet interface.

10) For all calibrations, the front panel interface assumes a certain calibration order in the data points. For calibrations via the UDP 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.

11) Calibrations can be performed from MIN to MAX range or MAX to MIN range provided the calibration steps precede sequentially.

Calibration records for 2 point, 6 point, and 21 point calibrations can be downloaded from the Kaman website: www.kamansensors.com.

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6.2 Calibration Fixturing

A good calibration starts with good calibration fixturing and reference. While in some cases the digiVIT 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. If adequate fixturing is not available, Kaman offers a calibration service.

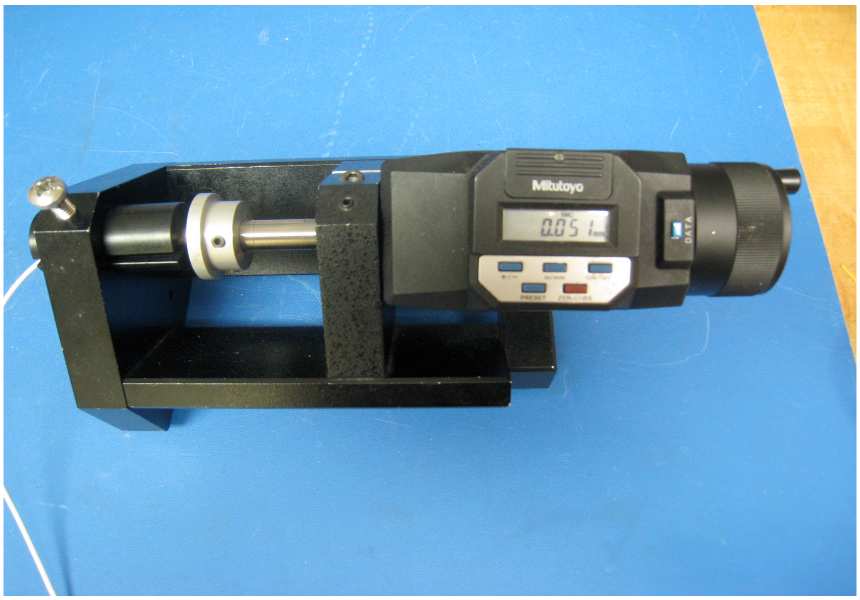

Figure 4 Typical Calibration Fixture

Refer to Appendix B for typical offset and range of recommended sensors.

6.3 2-Point Linear Calibration

Note: Any previous temperature compensation calibration will be voided when a 2 Pt. calibration is performed.

The 2 point calibration is the simplest calibration and assumes the inherent output from the sensor is linear. Over the first 10% of the range this is true in a general sense, however even with 5% of the range; non-linearity is typically on the order of 1% of the calibrated full scale output (though that is a pretty small absolute number typically). Over the standard full range linearity could be as large as 16%.

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) Select 'Cal Setup -> Lineariz Output -> 2 Pt. Lin. Cal.'. The unit will prompt 'Goto MAX Prs Entr'. With the sensor at MAX press the <enter> button. The unit will prompt 'Scanning Pls Wait' -- 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) The digiVIT will prompt 'Goto MIN Prs Entr'. Position the micrometer to the MIN (offset) position and press <enter>.

5) The digiVIT will prompt 'Goto 100% Prs Entr'. Position the micrometer to the MAX position and press <enter>.

The calibration is now complete. If the output reads 100.00% (or close to it) the calibration is good. If 'Cal Error' is displayed, the digiVIT did not acquire enough analog to digital converter counts between readings and the calibration sequence must be repeated.

6.4 6-Point Polynomial Calibration

Note: Any previous temperature compensation calibration will be voided when a 6 Pt. calibration is performed.

The 6 point calibration is a relatively simple calibration that generally yields excellent results. It assumes the inherent output from the sensor will have a reasonable fit to a 5th order polynomial -- generally a good assumption over most ranges. It will result in typical non-linearity on the order of 0.1% to 0.3%. 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 = 0.1mm 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) Select 'Cal Setup -> Lineariz Output -> 6 Pt. Poly Cal.'. The unit will prompt 'Goto MAX Prs Entr'. With the sensor positioned at full scale, press the <enter> button. The unit will prompt 'Scanning Pls Wait' -- 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) The digiVIT will prompt 'Goto MIN Prs Entr'. Go to the MIN position and press <enter>.

5) The digiVIT will prompt 'Goto 20% Prs Entr'. Go to the 20% (0.1mm in our example) position and press <enter>.

6) Repeat step 5 for 40%, 60%, and 80% positions

7) The digiVIT will prompt 'Goto 100% Prs Entr'. Position the micrometer to the MAX position and press <enter>.

The calibration is now complete. If the output reads 100.00% (or close to it) the calibration is good. If 'Cal Error' is displayed, the digiVIT did not acquire enough analog to digital converter counts between readings and the calibration sequence must be repeated.

6.5 21-Point Piecewise Calibration

Note: Any previous temperature compensation calibration will be voided when a 21 Pt. calibration is performed.

The 21 point calibration requires more displacement positions but is the most flexible and will calibrate to almost any curve as long as it is monotonic and there is enough output between sensor data points. If the fixturing is accurate it almost always yields excellent results. This calibration assumes nothing about the sensor output as it is a piecewise table lookup approach. It will result in typical non-linearity on the order of 0.1%. 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 = 0.025mm intervals.

1) Set the sensor flush with the target and move the micrometer to the MIN (offset) position. Zero the micrometer.

2) Position the sensor at the desired MAX (full scale range + offset) position.

3) Select 'Cal Setup -> Lineariz Output -> 21 Pt. Pcws Cal.'. The unit will prompt to 'Goto MAX Prs Entr'. With the sensor positioned at full scale, press the <enter> button. The unit will prompt 'Scanning Pls Wait' -- 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) The digiVIT will prompt 'Goto MIN Prs Entr'. Go to the MIN position and press <enter>.

5) The digiVIT will prompt 'Goto 5% Prs Entr'. Go to the 5% (0.025mm in our example) position and press <enter>.

7) Repeat step 5 for 10-95% positions.

5) The digiVIT will prompt 'Goto 100% Prs Entr'. Position the micrometer to the MAX position and press <enter>.

The calibration is now complete. If the output reads 100.00% (or close to it) the calibration is good. If 'Cal Error' displayed, the digiVIT did not acquire enough analog to digital converter counts between readings and the calibration sequence must be repeated.

6.6 2-Point Adjustment

Note: A 2 point adjustment **does not** void linearization or temperature compensation calibrations.

This procedure adjusts the calibration curve slightly for variations due to offset differences and slight target or loading differences. It is only for minor adjustments as it assumes the output curve has been affected linearly by environment differences.

1) Select 'Adjust Output -> 2 pt. Adjust' and press <enter>.

2) Position the sensor at the MIN (offset) position and press <enter>.

3) Position the sensor at the MAX (full range + offset) position and press <enter>.

The adjustment is now complete. If the output reads 100.00% (or close to it) the adjustment is good. If 'Cal Error' is displayed, the adjustment is not good, a full recalibration may be required.

6.7 3-Point Adjustment

Note: A 3 point adjustment **does not** void linearization or temperature compensation calibrations.

This procedure adjusts the calibration curve slightly for variations due to offset differences and slight target or loading differences. It is only for minor adjustments as it assumes the output curve has been affected linearly by environment differences.

1) Select 'Adjust Output -> 3 pt. Adjust' and press <enter>.

2) Position the sensor at the MIN (offset) position and press <enter>.

3) Position the sensor at the MID (mid range or 50%) position and press <enter>.

4) Position the sensor at the MAX (full range + offset) position and press <enter>.

The adjustment is now complete. If the output reads 100.00% (or close to it) the adjustment is good. If 'Cal Error' is displayed, the adjustment is not good, a full recalibration may be required.

6.8 Temperature Compensation (Electronics and Sensor)

While the digiVIT 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 digiVIT.

The Electronics can also be temperature compensated separately from the sensor using a built in temperature sensor for the compensation. The same prompts and procedure are used. Use caution in heating the electronics so that the plastic enclosure is not damaged by application of too high or too concentrated a heat source.

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 digiVIT 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 digiVIT will tend to compensate for it. In many cases the digiVIT 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) Select 'Cal Setup -> Temp Cmp Sensor' from the front panel. The prompt will read 'GotoD1T1 relC 0'. At this 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 then heat the sensor head (if the cable is going to be in the hot environment it should also be included). You will see the relC 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 rel C reads 10 or 12 or more that is sufficient. Let it cool down slightly to say 11 or even 9 (on the display) and press <enter>.

2) The prompt will read 'GotoD1T2 relC 8'. Let it cool down until the temperature is close to where it started, though it is not necessary to let it cool down all the way. Then press the <enter> button.

3) The prompt will read 'GotoD2T1 relC 1'. Reposition the sensor in the fixturing to be at a second displacement. Typically 10% of the range is good setting. Heat the sensor, let the transient go away, then press the <enter> button at a rel C of 10 or 12 (on the display

4) The prompt will read 'GotoD2T2 relC 9'. After the temperature goes down to near 1 or 2 (on the display) press the <enter> button.

5) The temperature compensation is complete.

Reference Appendix F for a Temperature Compensation Worksheet.

PART 7 – OTHER FEATURES

7.1 Limits & Relay

The digiVIT contains a solid state relay connected to pins 9 and 10 of the terminal block. 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 digiVIT must be connected by an Ethernet cable to a PC running console software. Reference PART 5 of this manual.

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

Note: The front panel display will show an “H” if sensor output is above the High limit. It will show an “L” if sensor output is below the Low limit.

7.2 IO bit/AUTOZERO

The IO bit (pin 8) 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 8 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%.

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APPENDIX A: COMMAND LIST

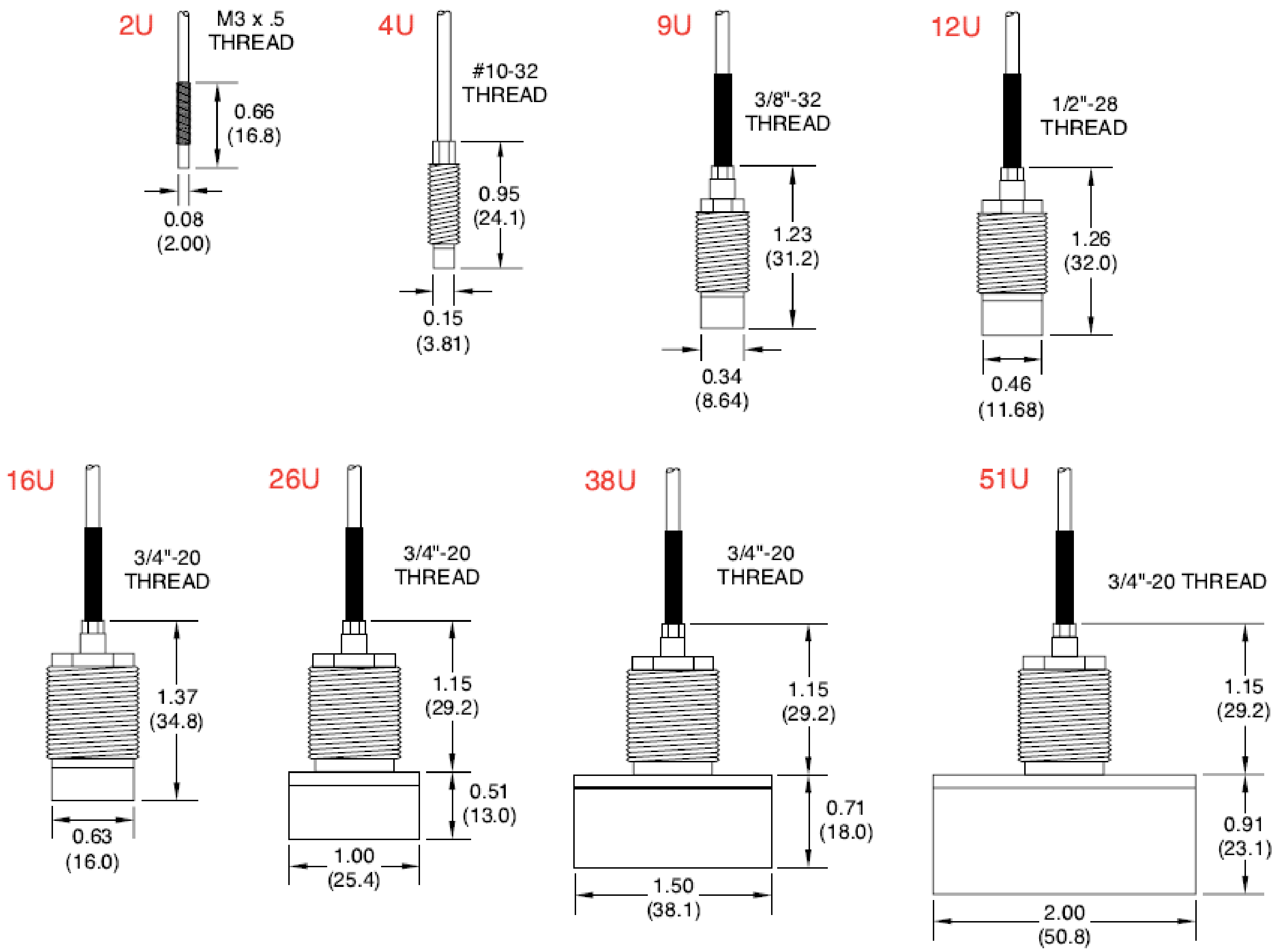
The following are the low level commands for the user to program an interface. Many of the setup commands are read or write. The command starts with an 'S' for a write (such as SCLL 20000) or an 'R' for a read (RCLL will read back the setting). Settings are stored in non-volatile system memory.

Command	Passlevel Required	Parameters	Returns	Comments
Monitor Commands				
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
AutoZero Function				
ZZ	NONE	NONE	--	Zeroes the output
ZC	NONE	NONE	--	Clears the zero on the output
Limit Setup				
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)
Ethernet Setup				
S(R)EA xxx xxx xxx xxx	USER	xx xxx xxx xxx = IP Address	IP Address	SET(READ) Ethernet IP Address Note: Separate Octets with spaces not '.'
S(R)EW xxxxx	USER	xx = port	UDP Writer Port	SET(READ) Ethernet Writer Port
S(R)ER xxxxx	USER	xx = port	UDP Reader	SET(READ) Ethernet Reader Port
REM	NONE		MAC	READ Ethernet MAC Address
Output Setup				
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

Command	Passlevel Required	Parameters	Returns	Comments
System				
RXR	NONE	NONE	Revision	Read Firmware Revision
U	NONE	Sets Passlevel	Passlevel 0-2	Unlocks for higher level control U KAMAN<ret> -- unlocks to User Level U<ret> -- sets password to normal level
MISC TIMER				
WC	NONE	NONE	Seconds	Watch Clock (seconds since power on)
WT	NONE	NONE	Ticks	Watch Ticks (Ticks since power on)
CALIBRATION				
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

APPENDIX B: digiVIT STANDARD PROBE OPTIONS

Although the digiVIT will work with nearly any single coil sensor and any conductive target, the following sensors have been characterized over standard ranges with both aluminum and steel targets.



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Characterized with an aluminum target		2U	4U	9U	12U	16U	26U	38U	51U
Offset	inch (mm)	0.002 (0.05)	0.005 (0.13)	0.010 (0.25)	0.016 (0.40)	0.020 (0.50)	0.032 (.80)	0.050 (1.20)	0.100 (2.50)
Short Range	inch (mm)	0.010 (0.25)	0.025 (0.60)	0.050 (1.25)	0.080 (2.00)	0.100 (2.50)	0.160 (4.00)	0.250 (6.00)	0.300 (7.5)
Standard Range	inch (mm)	0.020 ('0.50)	0.050 (1.30)	0.100 (2.50)	0.160 (4.00)	0.200 (5.00)	0.320 (8.00)	0.500 (12.0)	0.600 (15.0)
Extended Range	inch (mm)	0.030 (0.75)	0.070 (1.75)	0.150 (3.75)	0.240 (6.00)	0.320 (8.00)	0.500 (12.5)	0.800 (20.0)	1.000 (25.0)
Typical Specifications for stardard range, aluminum target, standard cable length									
Nonlinearity 6 pt calibration	±%FS	<0.3%							
Nonlinearity 21 pt calibration	±%FS	<0.1%							
Static Resolution	RMS%FS	<0.001%							
Resolution @ 100 Hz	RMS%FS	<0.01%							
Resolution @ 1000 Hz	RMS%FS	<0.02%							
Thermal Sensitity	%FS/°F (%FS/°C)	0.05 (0.1)							
Thermal Sensitity w/temp comp calibration	%FS/°F (%FS/°C)	0.01 (0.02)							

Probe Specifications with 6061 Aluminum, 2 m Cable

Characterized with a steel target		2U	4U	9U	12U	16U	26U	38U	51U
Offset	inch (mm)	NR	NR	NR	0.016 (0.40)	0.020 (0.50)	0.032 (.80)	0.050 (1.20)	0.100 (2.50)
Short Range	inch (mm)	NR	NR	NR	0.060 (1.5)	0.100 (2.50)	0.160 (4.00)	0.250 (6.00)	0.300 (7.5)
Standard Range	inch (mm)	NR	NR	NR	0.120 (3.00)	0.200 (5.00)	0.320 (8.00)	0.500 (12.0)	0.600 (15.0)
Extended Range	inch (mm)	NR	NR	NR	0.160 (4.00)	0.320 (8.00)	0.500 (12.5)	0.800 (20.0)	1.000 (25.0)
Typical Specifications for stardard range, steel target, standard cable length									
Nonlinearity 6 pt calibration	±%FS	NR	NR	NR	<0.3%	<0.3%			
Nonlinearity 21 pt calibration	±%FS	NR	NR	NR	<0.2%	<0.1%			
Static Resolution	RMS%FS	NR	NR	NR	<.001%	<0.001%			
Resolution @ 100 Hz	RMS%FS	NR	NR	NR	<0.01%	<0.01%			
Resolution @ 1000 Hz	RMS%FS	NR	NR	NR	<0.02%	<0.02%			
Thermal Sensitity	%FS/°F (%FS/°C)	NR	NR	NR	0.8 (1.6)	0.1 (0.2)			
Thermal Sensitity w/temp comp calibration	%FS/°F (%FS/°C)	NR	NR	NR	0.02 (0.04)	0.01 (0.02)			

NR = Not Recommended for 4130 targets

Probe Specifications with 4130 Steel, 2 m Cable

General Rules when using digiVIT with magnetic target materials:

1. On medium sized sensors (12U) 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: digiVIT TYPICAL SPECIFICATIONS

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

Parameter	Specification	Notes
Power Supply	+18-28V	Current will change with input
Input Current	0.13A	At +24V 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	200 Ω 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	0-50 °C	
Sensor DC Resistance	0.5 to 20 ohms	<0.5 ohms is 'bad sensor', >20 is 'no sensor'
Sensor Inductance	10uH to 50uH	Tested with sensors in this range. May be functional with sensors up to 10mH; function not guaranteed.

Specifications Subject to Change without Notice

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APPENDIX D: CALIBRATION EXAMPLES VIA ETHERNET INTERFACE

Calibrations using the Ethernet interface have the same procedure as the examples in Part 6 of the manual. Data is entered using UDP commands from a PC instead of front panel controls. To perform these procedures, the digiVIT must be connected by an Ethernet cable to a PC running console software. Reference PART 5 of this manual.

Refer to Appendix B for typical offset and range of recommended sensors.

D.1 - 2 Point Linear Calibration

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 UDP command **'CF'**. The unit will prompt 'Scanning Pls Wait' -- 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 2'** to take data, then **'C2'** to complete the calibration.

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

D.2 - 6 Point Polynomial Calibration

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 = 0.1mm 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 UDP command **'CF'.** The unit will prompt 'Scanning Pls Wait' -- 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 6'** to take data, then **'C6'** to complete the 6 point calibration.

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

D.3 - 21 Point Piecewise Calibration

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 = 0.025mm 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 UDP command **'CF'.** The unit will prompt 'Scanning Pls Wait' -- 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.

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

D.4 - 2 Point Adjustment

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 digiVIT 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.

D.5 - 3 Point Adjustment

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 digiVIT 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.

D.6 - Temperature Compensation (Electronics and Sensor)

While the digiVIT 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 digiVIT. 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 digiVIT 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 digiVIT will tend to compensate for it. In many cases the digiVIT 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) Select 'Cal Setup -> Temp Cmp Sensor' from the front panel. The prompt will read 'GotoD1T1 relC 0'. At this 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). You will see the relC 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 rel 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) The prompt will read 'GotoD1T2 relC 8'. 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'**.

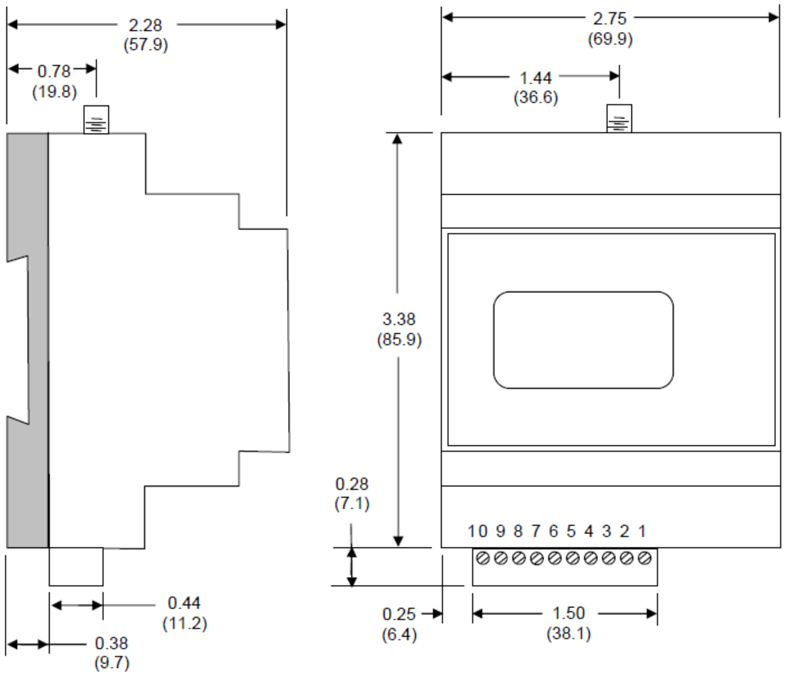
3) The prompt will read 'GotoD2T1 relC 1'. Reposition the sensor in the fixturing to be at a second displacement. Typically 10% of the range is good setting. Again it is best to heat it up, let the transient go away and press the enter button at a rel C of 10 or 12. After the transient has gone away, type **'CT 2'**.

4) The prompt will read 'GotoD2T2 relC 9'. After the 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.

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.

APPENDIX E: DIMENSIONS

Dimensions in inches (mm).



DigiVIT can be either DIN rail mounted or screw mounted with the mounting tabs (included).

DigiVIT with Mounting tabs

APPENDIX F: TEMPERATURE COMPENSATION WORKSHEET

Reference Section 6.8 for the detailed procedure.

Sales Order: ___________________________________

☐ **Standard TC (ΔT = 10°C)** ☐ **Sensor TC**

☐ **Custom TC (ΔT > 10°C)** ☐ **Electronics TC**

Offset: ______________ (mils or mm) Range: ______________ (mils or mm)

Display Units: _________________

Calculate Distances for TC

D1: _________ (Typically Range x 0.9, or 90% of Range)

D2: _________ (Typically Range x 0.1, or 10% of Range)

Calculate Temperatures for TC

T1: _________ (Typically = +10°C = 10 on display)
(Enter value per sales order if custom)

T2: _________ (Typically = ambient = 0 on display)
(Enter value per sales order if custom)

Recommended Procedure

1. Using from panel controls, set display to read % of range.
2. Select 'Cal Setup -> Temp Cmp Sensor' from the front panel.
3. Position the sensor at D1T1. Heat the sensor to T1 plus a few degrees. Let the sensor cool to T1 ± 2 degrees. Press <Enter>.
4. With the sensor still at D1, cool the sensor to T2 ± 2 degrees. Press <Enter>.
5. With the sensor temperature still at T2, re-position the sensor in the fixturing to D2. Press <Enter>.
6. With the sensor still at D2, heat the sensor to T1 plus a few degrees. Let the sensor cool to T1 ± 2 degrees. Press <Enter>.
7. Using the front panel controls, set the display to read the output per the sales order.
8. Compensation is complete.

APPENDIX G: DIGITAL FILTER

The digiVIT (version 2 and higher) can sample at; 5,000, 10,000, 20,000 or 22,500 samples per second. Previous versions have sample rates of 5,000 and 10,000 sps only. The digiVIT 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:

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

where:

Output = the output of the system (before linearization)
Input = ADC output for a given sample
n = the integer value of the filter
O_{-1} = 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^n/sample rate). For a sample rate of 5,000 samples per second and n = 3, the time constant (τ) will be approximately (2^3/5000) 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 $f_{3dB} \times t_r = 0.35$ for this simple case. In this case the bandwidth (-3dB) is approximately: f_{3dB} = 0.35/.00352 ~ 100 Hz. In the digiVIT display for filter selection, the display shows the value of

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

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_r,s	f_{-3dB},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	τ,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	τ,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	τ,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

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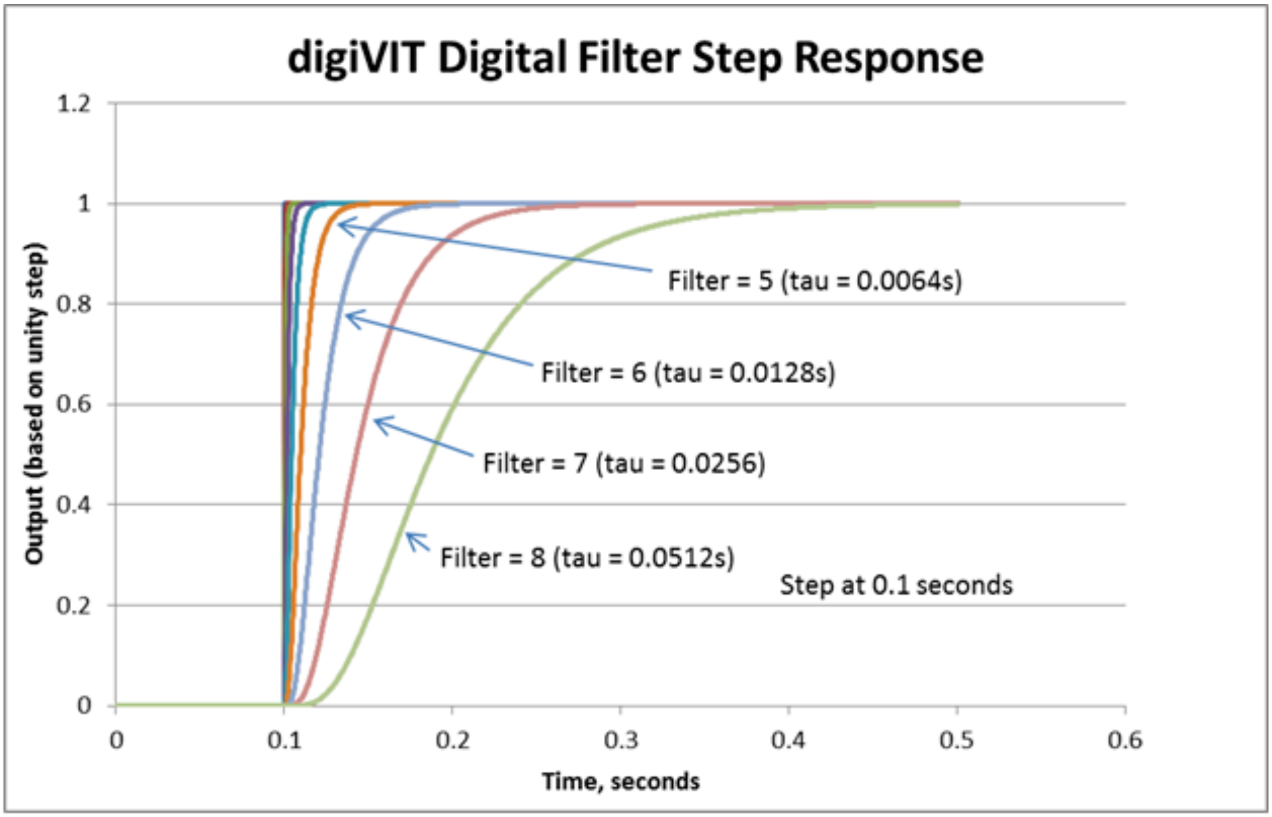
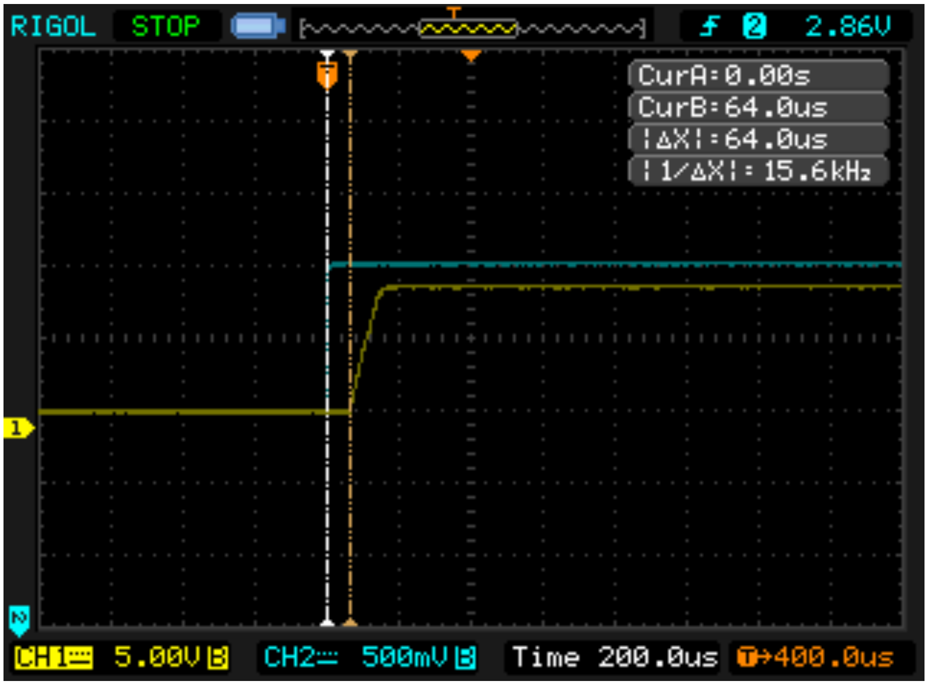
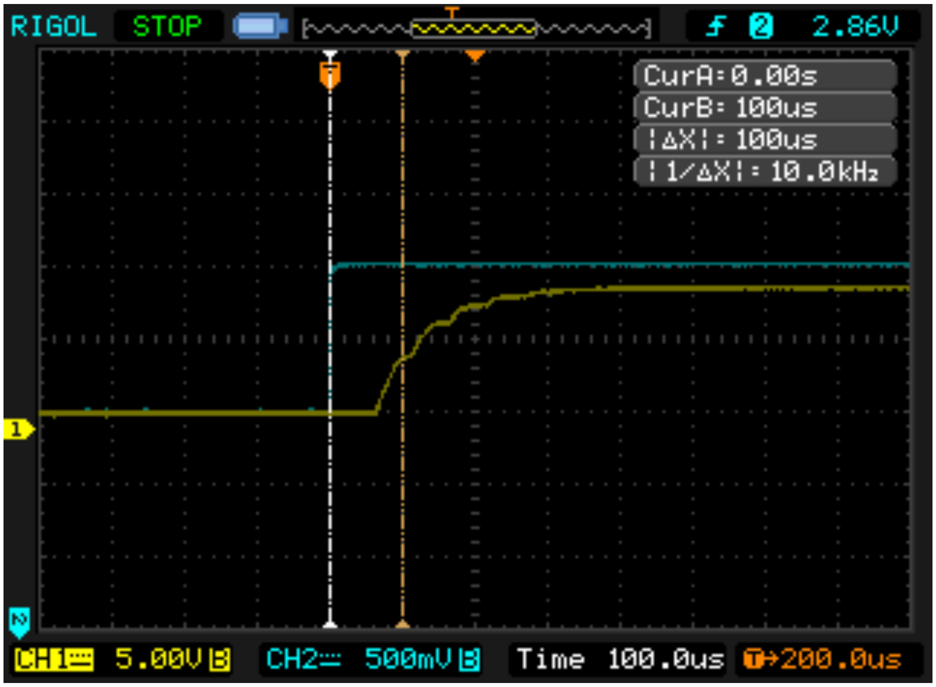
The Time Constants are based on the frequency. Note that for a step input, 1 time constant later the output will be at 63% of the final value. At 3 time constants, the output will be at 95% of the final value. This is illustrated in the table below.



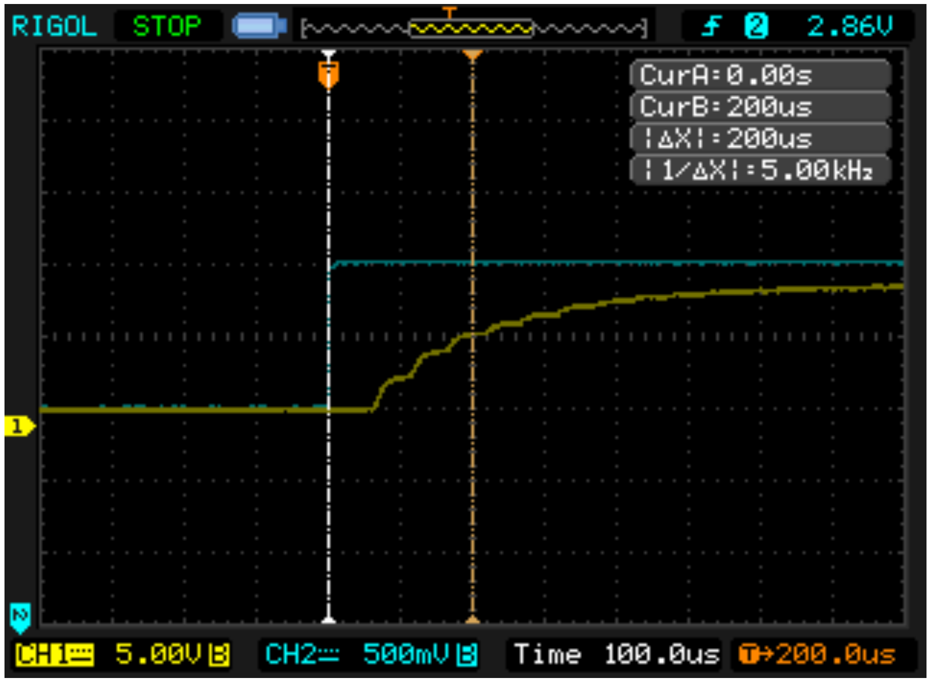
The following oscilloscope screen captures show the real delay and the effect of the filtering on a step input with the sample rate set to 20 kHz:



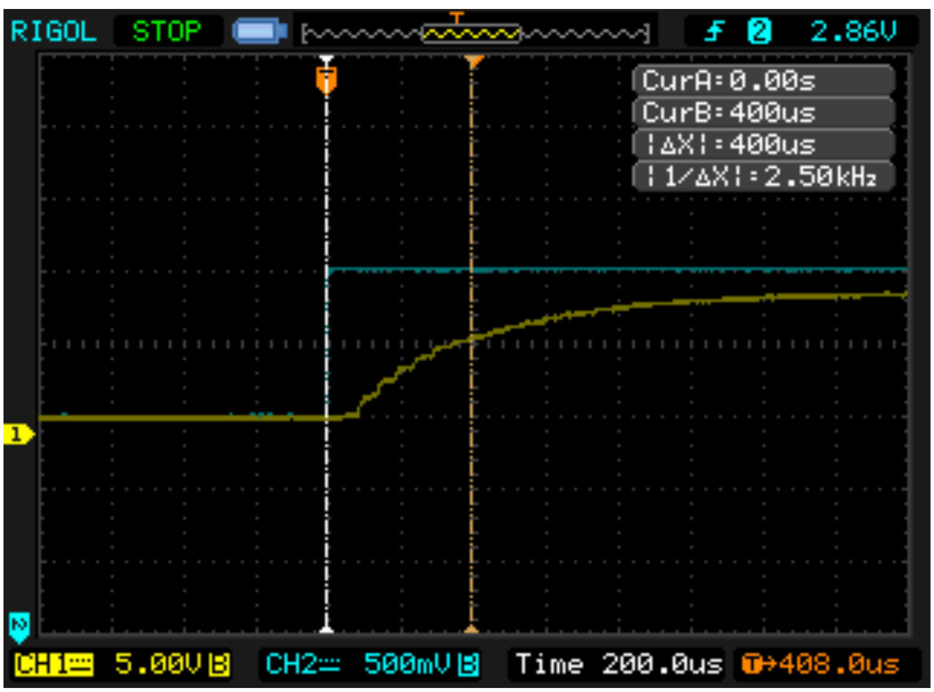
n=-0



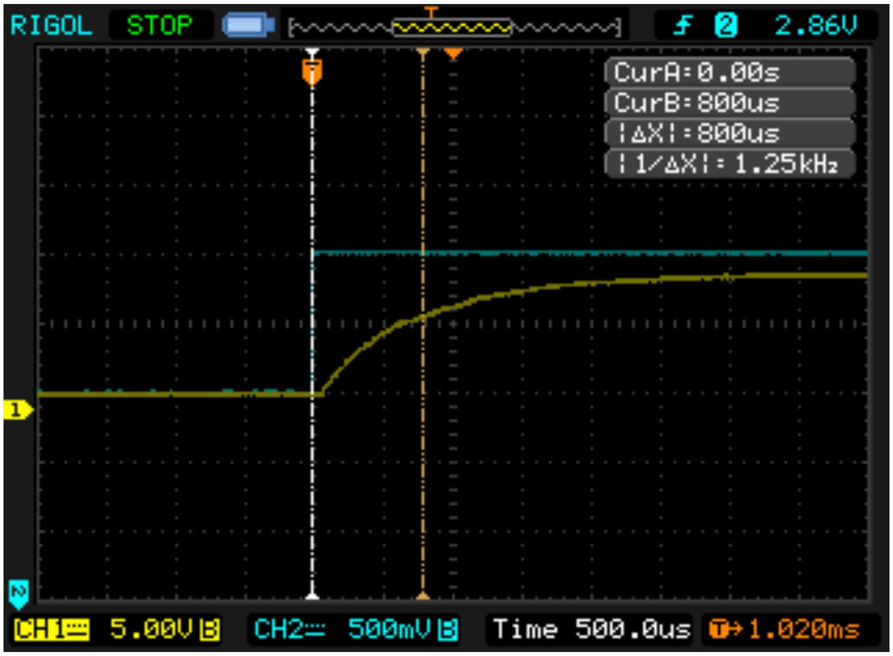
n=1, τ = 100 microseconds



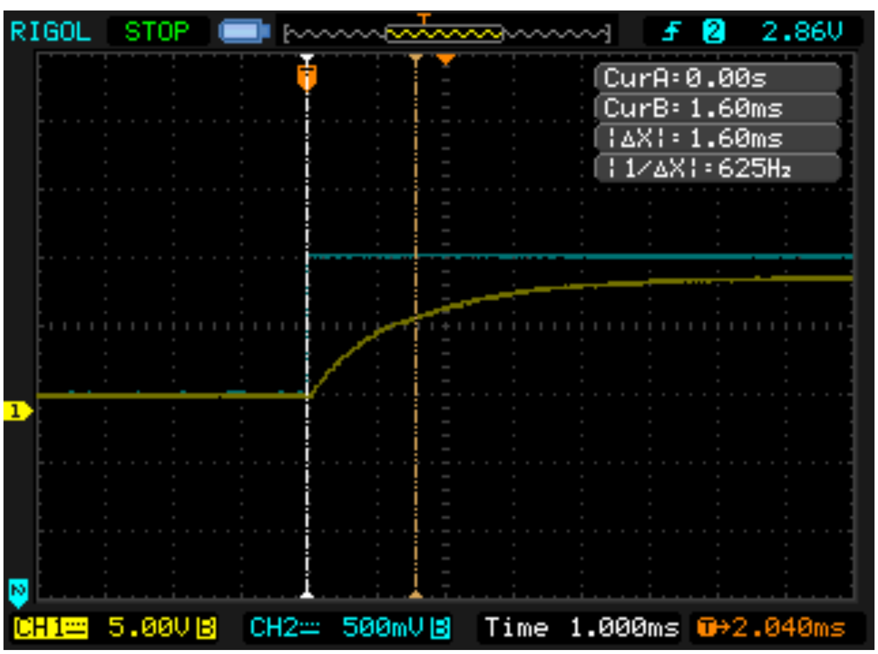
n=2, τ = 200 microseconds



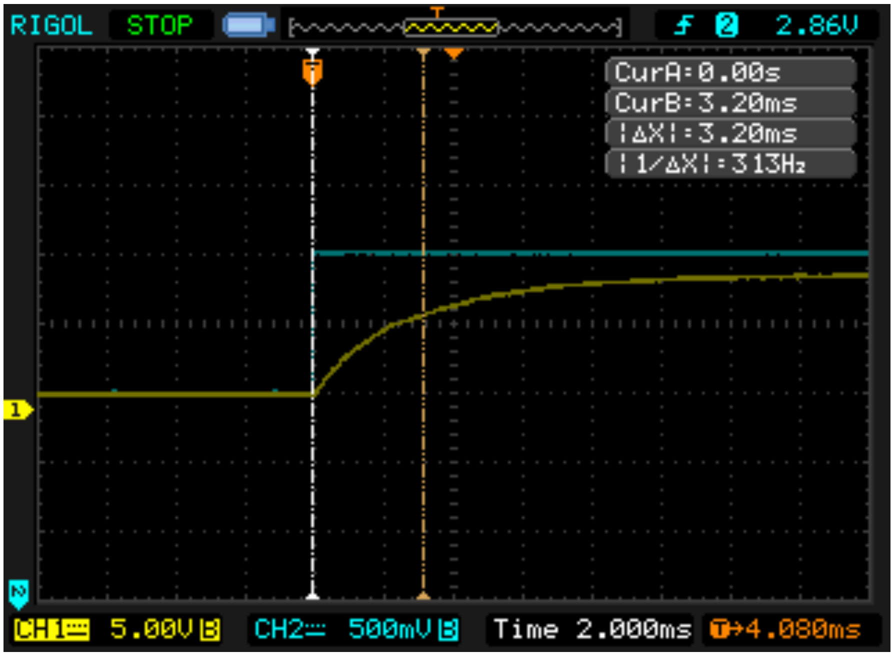
n=3, τ = 400 microseconds



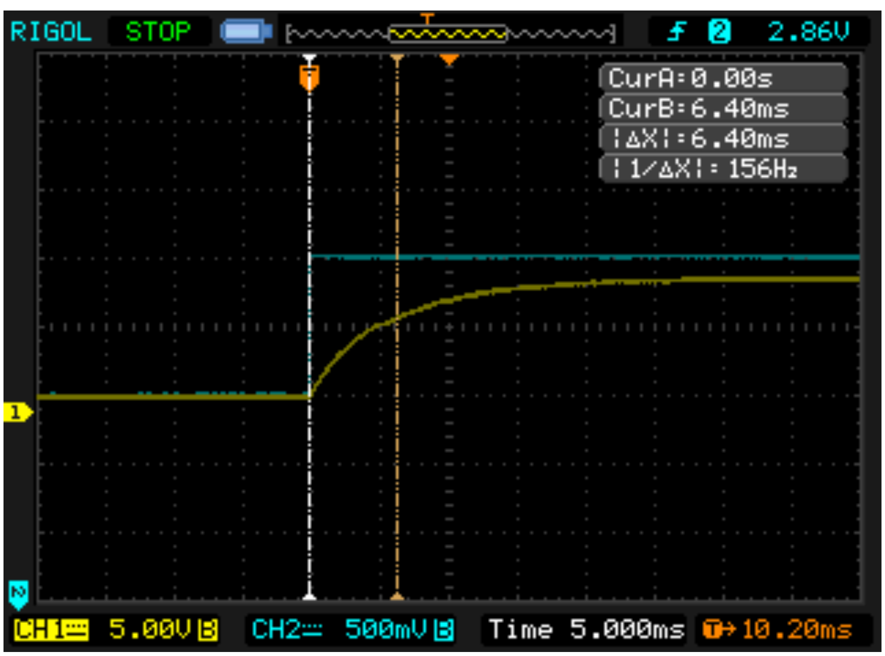
n=4, τ = 800 microseconds



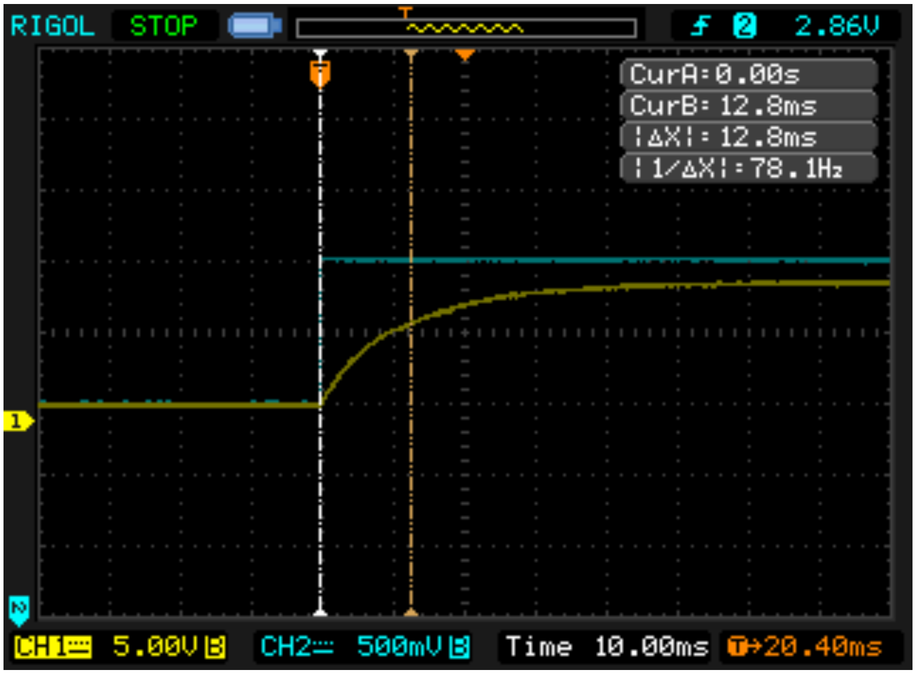
n=5, τ = 1.6 milliseconds



n=6, τ = 3.2 milliseconds



n=7, τ = 6.4 milliseconds



n=8, τ = 12.8 milliseconds

APPENDIX H: SOFTWARE LICENSE AGREEMENT

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