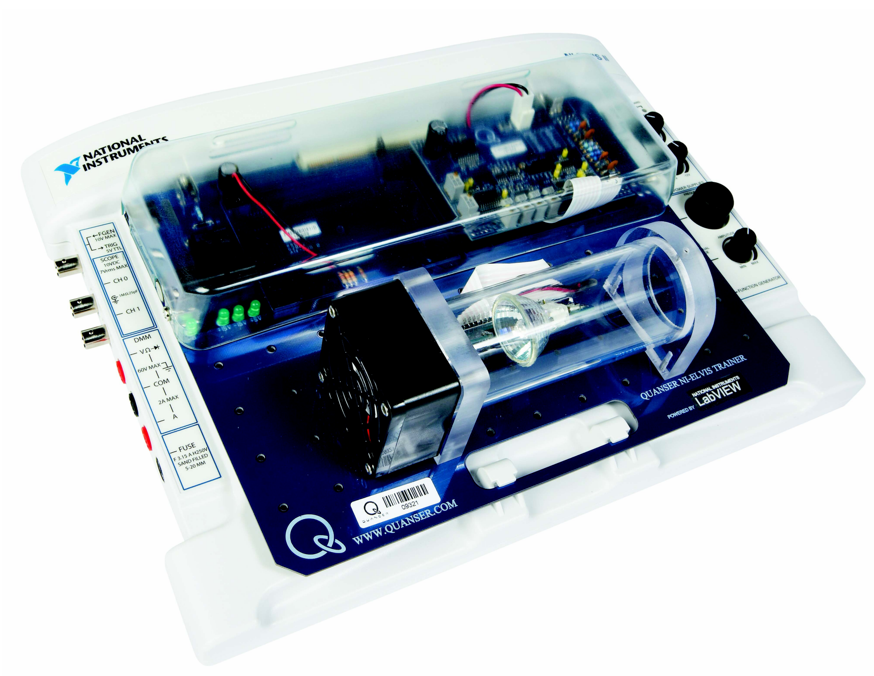
QNET-012 HVAC Trainer

Quanser Engineering Trainer for NI-ELVIS

QNET Heating and Ventilation Trainer



Student Manual

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1. Introduction

This manual contains experimental procedures and lab exercises for the QNET Heating and Ventilation Trainer (HVACT). The HVACT is depicted in Figure 1 and the hardware of the device is explained in Reference [1].

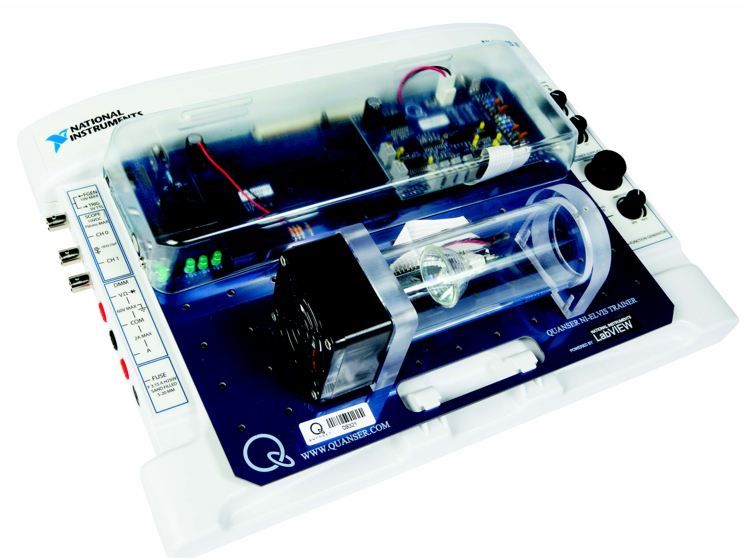

Figure 1: QNET HVAC trainer on ELVIS II.

The prerequisites to run the LabVIEW Virtual Instruments (VIs) for the HVACT are listed in Section 2 and described in Section 3. The in-lab procedures are given in Section 4 and split into two sections: on-off control and PI control. In Section 4.1, a relay switch is used to regulate the temperature inside the chamber. This response is then used to establish a simple model of the plant. In Section 4.2, a PI compensator is used to control the temperature. This section includes exercises that demonstrates the effect of proportional and integral control, integrator anti-windup, and set-point weight. Students can then use the model they derived to design PI gains that meet certain specifications. The exercises are given within the lab procedures and labeled "**Exercise**". In that case, enter your answer in the corresponding exercises number in the corresponding section.

2. Prerequisites

The following system is required to run the QNET HVAC Trainer virtual instruments:

- ✔ PC equipped with either:
  - ✔ NI-ELVIS I and an NI E-Series or M-Series DAQ card.
  - ✔ NI ELVIS II

- ✔ Quanser Engineering Trainer (QNET) module.
- ✔ LabVIEW 8.6.1 with the following add-ons:
  - ✔ DAQmx
  - ✔ Control Design and Simulation Module
  - ✔ *When using ELVIS II*: ELVISmx installed for required drivers.
  - ✔ *When using ELVIS I*: ELVIS CD 3.0.1 or later installed.

⚠ **If these are not all installed then the VI will not be able to run!** Please make sure all the software and hardware components are installed. If an issue arises, then see the troubleshooting section in Reference [1].

3. HVACT Virtual Instruments

3.1. Summary

Table 1 below lists and describes the HVACT LabVIEW Vis supplied with the **QNET CD**.

VI	*Description*
QNET_HVACT_On_Off_Control.vi	Control temperature using on-off control.
QNET_HVACT_PI_Control.vi	Control temperature using a proportional-integral (PI) regulator.

Table 1: HVACT VIs supplied with the QNET CD.

3.2. Description

3.2.1. On-Off Control

The HVACT On-Off Control VI implements a relay to control the temperature of the chamber. This VI can also be used to model the dynamics between the heater voltage and the temperature. Table 2 lists and describes the main elements of the QNET-HVACT On-Off Control virtual instrument user interface. Every element is uniquely identified through an ID number and located in Figure 2.

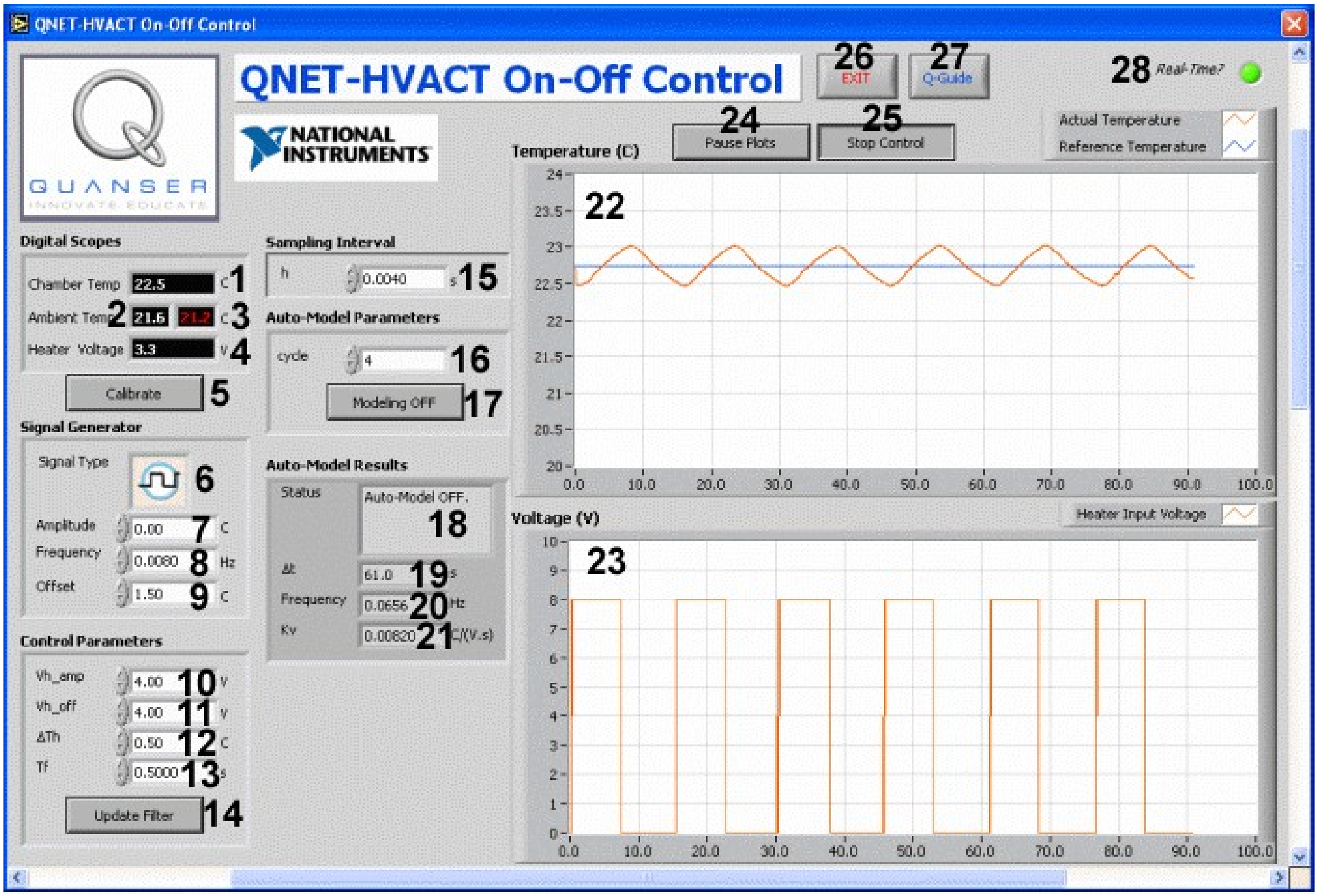

Figure 2: QNET-HVACT On-Off Control virtual instrument.

ID #	*Label*	*Parameter*	*Description*	*Unit*
1	Chamber Temp	T_c	Temperature inside chamber numeric display.	°C
2	Ambient Temp	$T_{a,m}$	Temperature outside chamber numeric display (i.e. measured room temperature).	°C
3		T_a	Latched ambient temperature that is added to reference temperature from Signal Generator	
4	Heater Voltage	V_h	Heater input voltage numeric display.	V
5	Calibrate		Sets the red latched ambient temperature to the measured ambient temperature.	
6	Signal Type		Type of signal generated for the temperature reference.	
7	Amplitude		Generated signal amplitude input box.	°C
8	Frequency		Generated signal frequency input box.	Hz
9	Offset		Generated signal offset input box.	°C
10	Vh_amp	$V_{h,amp}$	Heater voltage relay amplitude input box.	V
11	Vh_off	$V_{h,off}$	Heater voltage relay offset input box.	V
12	ΔTh	ΔT_h	Heater relay hysteresis width.	°C
13	Tf	T_f	Time constant of filter for measured signal input box.	s
14	Update Filter		Updates the filter transfer function with the time constant.	
15	h	h	Sampling time interval of virtual instrument input box.	s
16	cycle		Number of relay cycles to take into account when performing auto-model procedure.	
17	Modelling OFF		Click on this button to begin auto-model procedure.	
18	Status		Output box that reports the current result of the auto-modeling procedure.	
19	dt		Total time duration of cyles used for auto-modeling	
20	Frequency		Frequency of cycles.	
21	Kv	K_v	Model gain calculated from auto-model procedure: slope of temperature response	°C/(V.s)

			used in open-loop transfer function.	
22	Temperature	T_c, T_r	Scope with measured chamber temperature (in red) and reference temperature (in blue).	°C
23	Voltage	V_m	Scope with applied motor voltage (red).	V
24	Pause Plots		Pauses the Temperature and Voltage scopes.	
25	Start Control		When not pressed, the control output is ignored and a voltage of zero is applied to the motor.	
26	EXIT		Stops the LabVIEW virtual instrument from running.	
27	Q-Guide		Loads the QNET Interactive Learning Guide experiment procedure for this VI.	
28	Real-Time?		The green light indicates that the sampling rate is being maintained.	

Table 2: Nomenclature of QNET-HVACT On-Off Control VI

Remark: The reference temperature is relative to the latched ambient temperature, ID #3 in Table 2. The reference temperature is equal to the sum of the signal generated from the Signal Generator and the *latched* ambient temperature.

3.2.2. PI Control

In the QNET HVACT PI Control VI, a proportional-integral compensator is used to control the temperature of the chamber. The PI control includes anti-windup and set-point weight strategies. Table 3 lists and describes the main elements of the QNET-HVACT PI Control virtual instrument user interface. Every element is uniquely identified through an ID number and located in Figure 3.

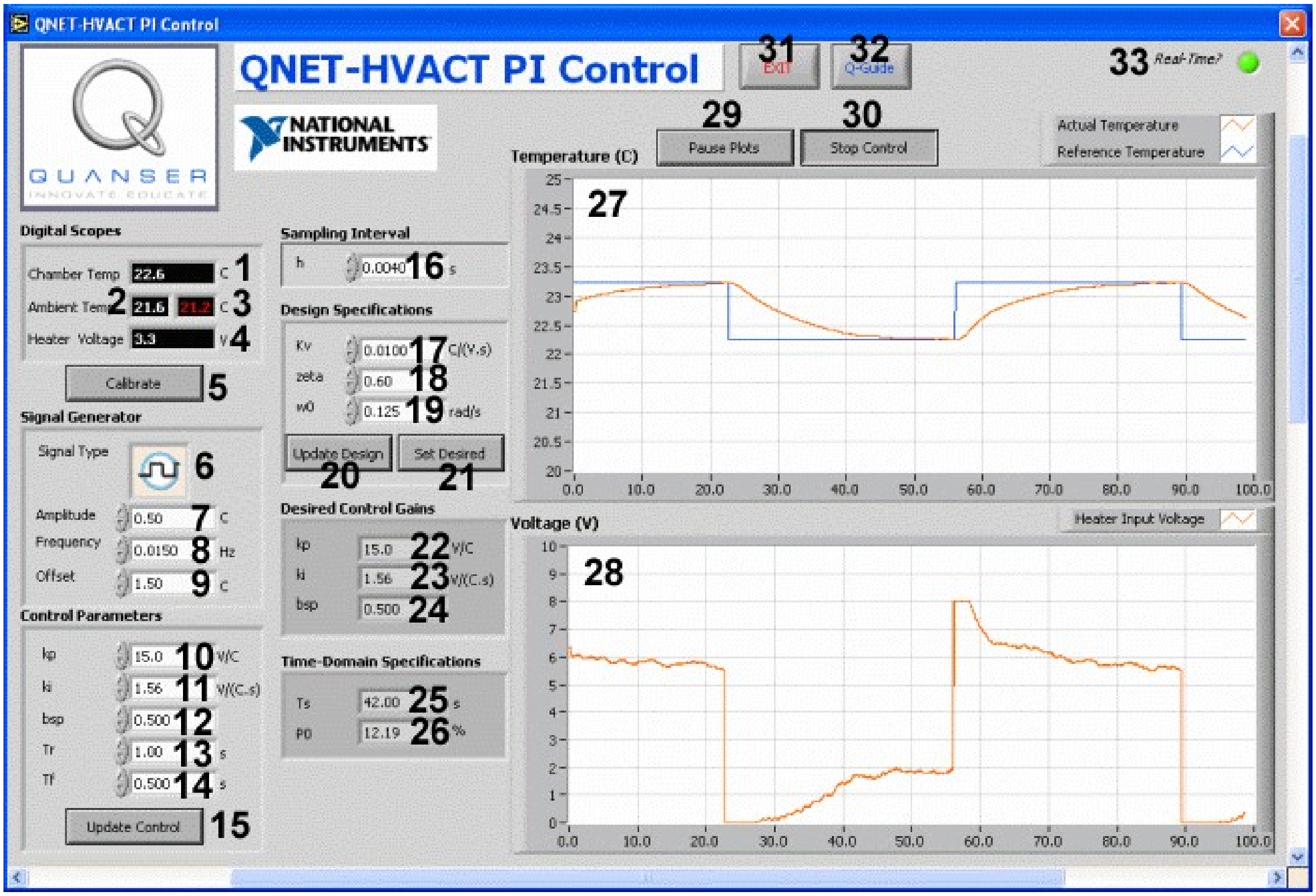

Figure 3: Nomenclature of QNET-HVACT PI Control VI.

#	Label	Parameter	Description	Unit
1	Chamber Temp	T_c	Temperature inside chamber numeric display.	^oC
2	Ambient Temp	$T_{a,m}$	Temperature outside chamber numeric display (i.e. measured room temperature).	^oC
3		T_a	*Latched* ambient temperature that is added to reference temperature from *Signal Generator*.	
4	Heater Voltage	V_h	Heater input voltage numeric display.	V
5	Calibrate		Sets the red *latched* ambient temperature to the measured ambient temperature.	
6	Signal Type		Type of signal generated for the temperature reference.	
7	Amplitude		Generated signal amplitude input box.	^oC
8	Frequency		Generated signal frequency input box.	Hz
9	Offset		Generated signal offset input box.	^oC
10	kp	k_p	Controller proportional gain input box.	$V/^oC$
11	ki	k_i	Controller integral gain input box.	$V/(^oC.s)$
12	bsp	b_{sp}	Controller set-point gain input box.	
13	Tr	T_r	Anti-windup tracking time constant.	s
14	Tf	T_f	Time constant of filter for measured signal input box.	s
15	Update Control		Apply control parameters to implemented digital controller running in VI.	
16	h	h	Sampling time interval of virtual instrument input box.	s
17	Kv	K_v	Model gain calculated from auto-model procedure: slope of temperature response used in open-loop transfer function.	$^oC/(V.s)$
18	zeta	ζ	Damping ratio control specification input box.	
19	w0	ω_0	Natural frequency control specification input box.	
20	Update Design			
21	Set Desired			
22	kp	$k_{p,d}$	Desired proportional gain to meet *zeta, w0*, and *p0* specification output box.	$V/^oC$
23	ki	$k_{i,d}$	Desired integral gain to meet *zeta* and *w0* specification output box.	$V/(^oC.s)$
24	bsp	$b_{sp,d}$	Desired set-point weight to meet *zeta* and *w0* specification output box.	
25	Ts	t_s	Simulated settling time output box.	s

26	PO	PO	Simulated percentage overshoot.	%
27	Temperature	T_c, T_r	Scope with the measured chamber temperature (in red) and the reference temperature (in blue).	^{o}C
28	Voltage	V_m	Scope with applied motor voltage (red).	V
29	Pause Plots		Pauses the *Temperature* and *Voltage* scopes.	
30	Start Control		When not pressed, the control output is ignored and a voltage of zero is applied to the motor.	
31	Q-Guide		Loads the QNET Interactive Learning Guide experiment procedure for this VI.	
32	EXIT		Stops the LabVIEW virtual instrument from running.	
33	Real-Time?		The green light indicates that the sampling rate is being maintained.	

Table 3: Nomenclature of QNET-HVACT PI Control VI.

4. In-Lab Experiments

4.1. On-Off Control

4.1.1. Startup

1. Open the QNET_HVACT_On_Off_Control.vi.
2. Ensure the correct *Device* is chosen, as shown in Figure 4.

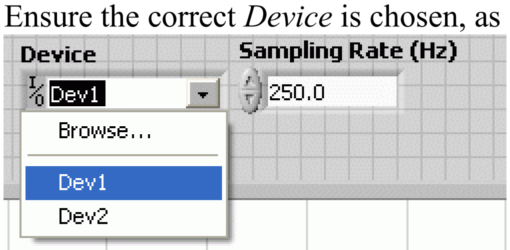

Figure 4: Selecting correct device.

3. Run the QNET_HVACT_On_Off_Control.vi shown in Figure 5, below..
4. The cooling fan is automatically activated when the *Prototyping Board Power* switch on the ELVIS unit is on. Let the actual temperature, *Tc* , in the *Temperature (C)* scope settle until it stops decreasing.
5. Adjust the *Temperature (C)* scope scales to see both the reference and actual temperatures (see Reference [1] for help).
6. As illustrated in Figure 5, calibrate the temperature sensors by clicking on the *Calibrate* button. This will align the chamber temperature, *Tc*, to the measured ambient temperature, *Ta*.
7. Activate the control by clicking on the *Heater OFF* button (in the top-right corner of Figure 5).

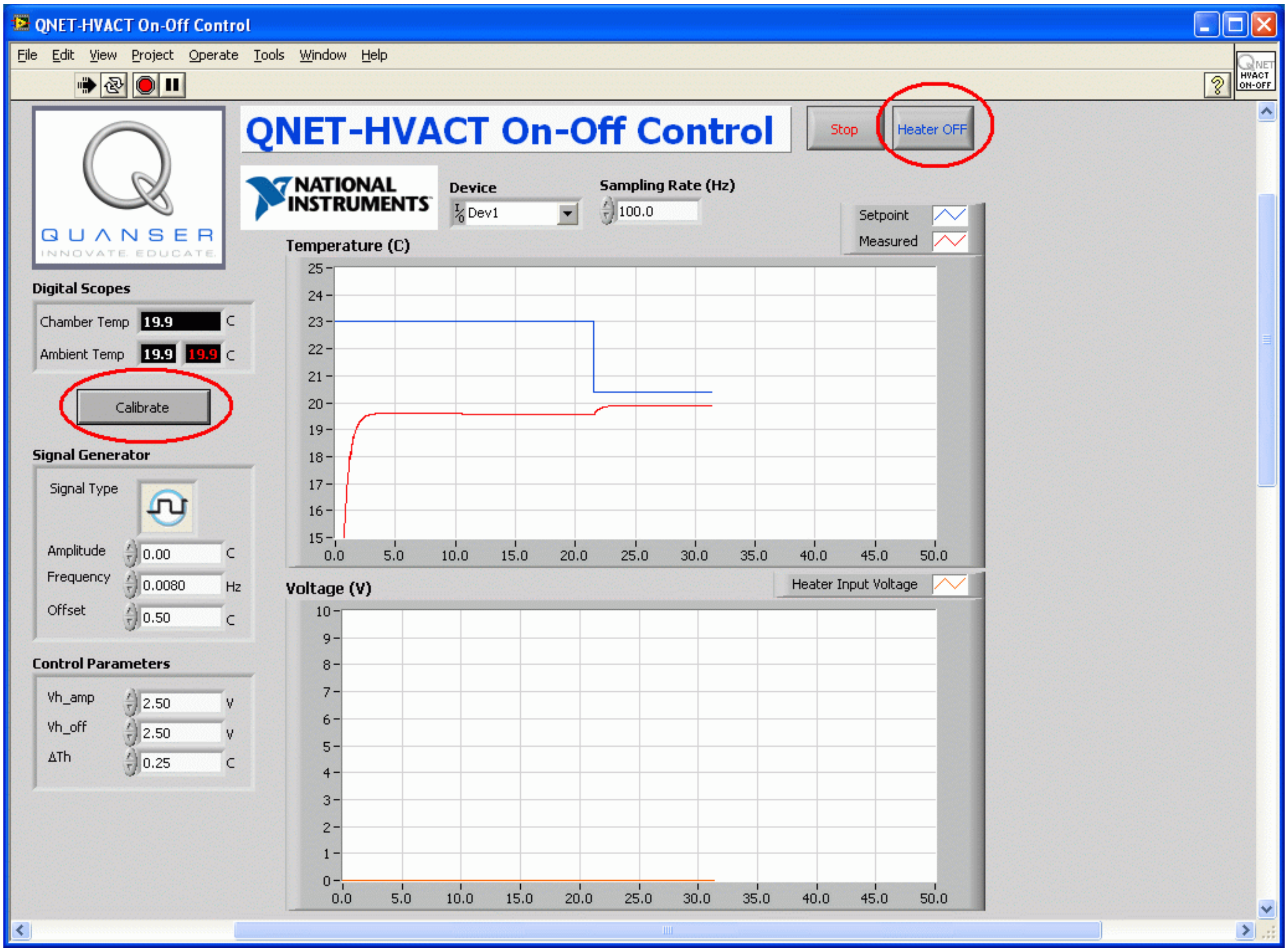

Figure 5: Calibrating the temperature in the QNET HVACT On-Off Control VI.

4.1.2. Relay Control

1. Ensure the QNET_HVACT_On_Off_Control.vi is running and has been calibrated as instructed in Section 4.1.1. When running, the VI should look similar to Figure 6.
2. In the *Signal Generator* section set:
   Amplitude = 0 °C
   Frequency = 0.008 Hz
   Offset = 0.5 °C
3. Examine the actual temperature (red) and reference temperature (blue) responses in the *Temperature (C)* scope.
4. **Exercise 1**: Gradually vary the *Offset* in the *Signal Generator* between 0.5 °C and 2 °C. How is the reference temperature, *Tr*, in the *Temperature (C)* scope is set? Attach a sample temperature response.
5. **Exercise 2**: Vary the relay amplitude, *Vh_amp*, in the *Control Parameters* section. Explain how the heater voltage affects the temperature variation and, in particular, observe the frequency and amplitude of the chamber temperature. Attach a representative temperature response.

6. **Exercise 3**: Explain the effect of changing the relay mean, *Vh_off*. Attach a temperature response.
7. **Exercise 4**: Examine the effects of changing the relay width (or hysteresis), *DTh*, between 0.01 °C and 1.00 °C. Give a short explanation and attach a temperature response with a narrow and wide hysteresis.
8. Click on the *Stop* button to stop running the VI.

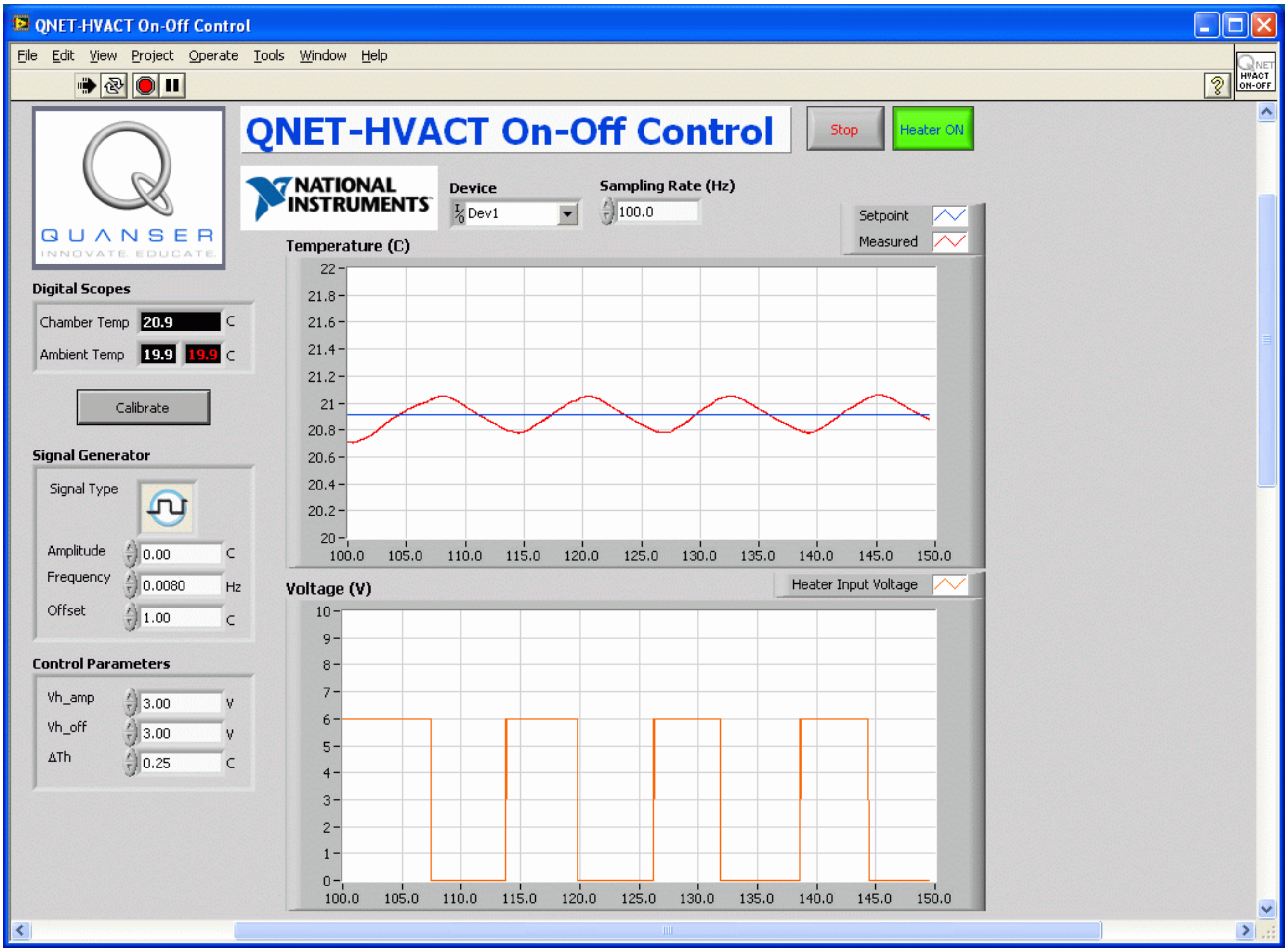

Figure 6: QNET-HVACT On-Off Control VI.

4.1.3. Modeling

1. Ensure the QNET_HVACT_On_Off_Control.vi is running and has been calibrated as instructed in Section 4.1.1. When running, the VI should look similar to Figure 6.
2. In the *Signal Generator* section set:

   Amplitude = 0 °C
   Frequency = 0.008 Hz
   Offset = 1.50 °C.
3. In the *Control Parameters* section set:

Vh_amp = 4.0 V
Vh_off = 4.0 V
DTh = 0.50 °C.

4. Adjust the *Temperature (C)* scope scales to see both the reference and actual temperatures (see Reference [1] for help).
5. Adjust the *Offset* in the *Signal Generator* to obtain a relatively symmetrical oscillation (i.e. the rate of increase and decrease should be similar).
6. **Exercise 5**: Observe the heater voltage and the chamber temperature. As discussed in Reference [2], this can be modeled by the simple transfer function $P(s) = K_v/s$. Find parameter K_v that would describe the relation between the voltage and the temperature signals. Make sure you fill Table 4 and attach both the temperature and voltage responses used to find K_v.
7. Click on the *Stop* button to stop running the VI.

4.1.4. Exercises

Exercise 1: Setting the Reference Temperature

0	1	2

Exercise 2: Changing Relay Amplitude

0	1	2

Exercise 3: Changing Relay Mean

0	1	2

Exercise 4: Changing Relay Hysteresis Width

0	1	2

Exercise 5: Find Model Parameter

0	1	2

Parameters	*Symbol*	*Value*	*Units*
Temperature change	ΔT_c		°C
Heater voltage change	ΔV_h		V
Ramp time	Δt		s
Ramp slope	K_v		°C/(V.s)

Table 4: HVACT model parameter.

4.2. PI Control

4.2.1. Startup

1. Run the QNET_HVACT_PI_Control.vi, as shown in Figure 7, below.
2. The cooling fan is automatically activated when the *Prototyping Board Power* switch on the ELVIS unit is on. Let the actual temperature in the *Temperature (C)* scope settle until it stops decreasing.
3. Adjust the *Temperature (C)* scope scales to see both the reference and actual temperatures (click here for help).
4. As illustrated in Figure 5, above, calibrate the temperature sensors by clicking on the *Calibrate* button. This will align the chamber temperature, *Tc*, to the measured ambient temperature, *Ta*.
5. Activate the control by clicking on the *Heater OFF* button (in the top-right corner).
6. Adjust the *Temperature (C)* scope scales to see both the reference and actual temperatures (see Reference [1] for help).

4.2.2. PI Control with Anti-Windup

1. Ensure the QNET_HVACT_PI_Control.vi is running and has been calibrated as instructed in Section 4.2.1.
2. In the *Signal Generator* section set:
   Amplitude = 0.50 °C
   Frequency = 0.0200 Hz
   Offset = 1.50 °C
3. In *Control Parameters* set:
   kp = 4.00 V/°C
   ki = 0.5 V/(°C.s)
   bsp = 1.00
   Tr = 1.00 s
4. Examine the temperature response to the square wave input.
5. **Exercise 1**: Set *ki* to 0 V/(°C.s) and change the proportional gain *kp* between 2 V/°C and 10 V/°C. Explain the effect proportional gain has on the temperature control performance. Attach a temperature response when using a low and high proportional gain.

6. **Exercise 2**: Set *kp* to 0.5 V/(°C.s) and change the integral gain *ki* between 0.25 V/(°C.s) and 2.0 V/(°C.s) and observe its effect on the temperature control performance. Show the temperature response with a low and high integral gain.
7. Click on the *Stop* button to stop running the VI.

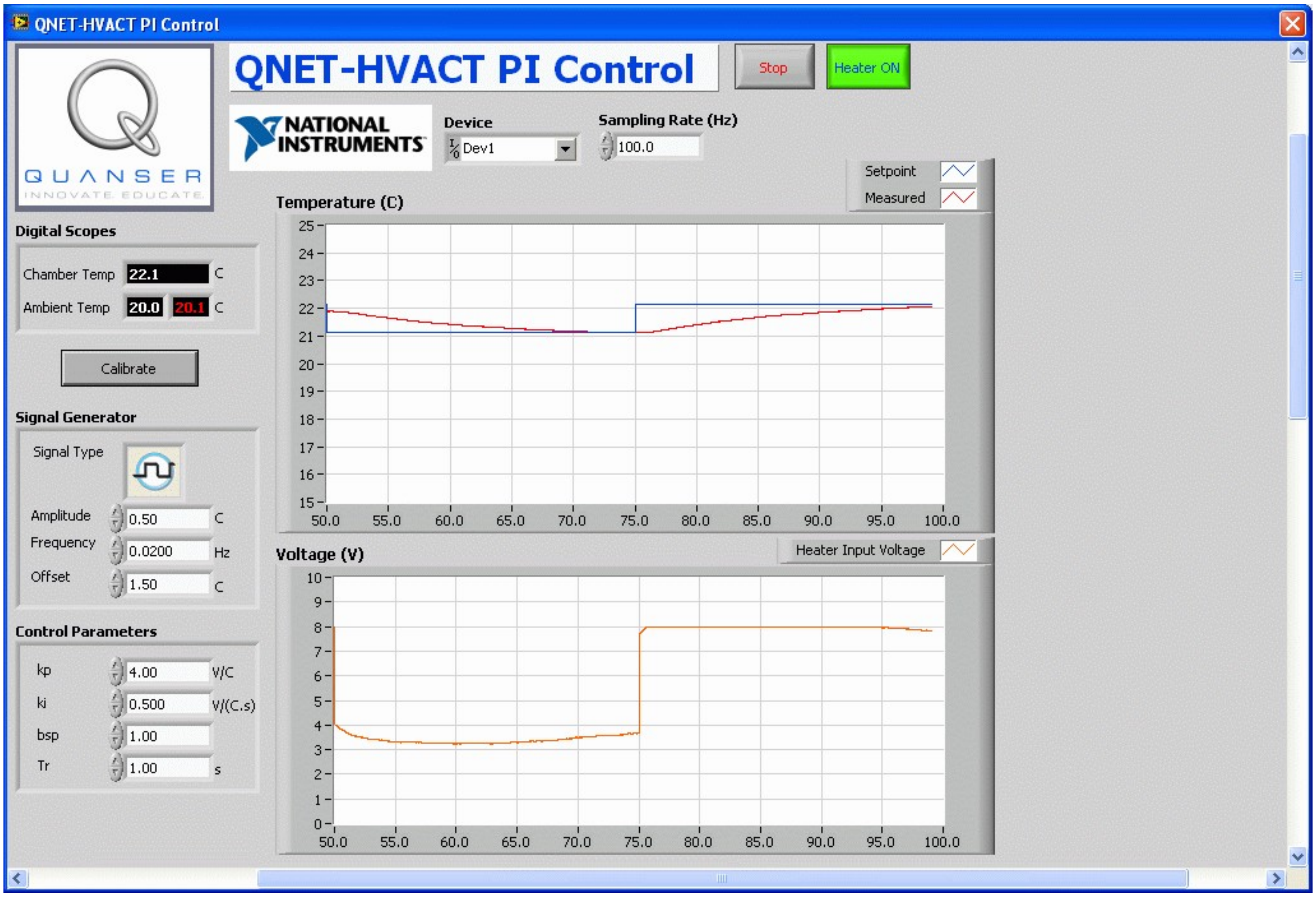

Figure 7: QNET-HVACT PI Control VI.

4.2.3. Effect of Saturation and Windup

1. Ensure the QNET_HVACT_PI_Control.vi is running and has been calibrated as instructed in Section 4.2.1.
2. In the *Signal Generator* section set:
   Amplitude = 0.75 °C
   Offset = 1.50 °C
   Frequency = 0.0200 Hz
3. In *Control Parameters* set:
   kp = 8.00 V/°C
   ki = 4.00 V/(°C.s)
   bsp = 1.00
   Tr = 100.0 s

4. **Exercise 3**: What effect does increasing the anti-windup reset parameter have on the control signal and on the temperature response? Attach a response of the temperature and heater voltage. See Reference [2] for more information on anti-windup.
5. In the *Control Parameters* section, set *Tr* = 1.0 s.
6. **Exercise 4**: What effect does decreasing T_r have on the control signal and on the temperature response? Capture the temperature response as well as the heater voltage.
7. Click on the *Stop* button to stop running the VI.

4.2.4. Effect of Set-Point Weight

1. Ensure the QNET_HVACT_PI_Control.vi is running and has been calibrated as instructed in Section 4.2.1.
2. In *Signal Generator* set:
   Amplitude= 0.50 °C
   Offset = 1.50 °C
   Frequency = 0.0200 Hz.
3. In *Control Parameters* set:
   kp = 8.00 V/°C
   ki =1.00 V/(°C.s)
   bsp = 0.00
   Tr = 1.00 s
4. **Exercise 5**: Examine the response of the measured temperature in the *Temperature (C)* scope as well as the input heater voltage in the *Voltage (V)* scope. Attach the temperature and heater voltage responses.
5. Try the controller with a set-point weight of 1.00.
6. **Exercise 6**: Study what effects raising *bsp* has on the measured temperature signal in the *Temperature (C)* scope and the control signal shown in the *Voltage (V)* scope. Capture the temperature response and its corresponding heater voltage.
7. Click on the *Stop* button to stop running the VI.

4.2.5. PI Control According to Specifications

1. Ensure the QNET_HVACT_PI_Control.vi is running and has been calibrated as instructed in Section 4.2.1.
2. In *Signal Generator* set:
   Amplitude = 0.50 °C
   Offset= 1.50 °C
   Frequency = 0.0200 Hz
3. **Exercise 7**: Find the proportional and integral gains, i.e. kp and ki, needed for the response to satisfy the following specifications:
   zeta = 0.60
   w0 = 0.125 rad/s
   Use the model gain found previously in Section 4.1.3 and the design principles outlined in Reference [2].
4. Enter the obtained control gains in the *Control Parameters* section.

5. **Exercise 8**: Examine the measured temperature response using your design PI gains. How is the performance of the controller compared to the previous controller?Attach the temperature and the heater voltage responses.
6. Click on the *Stop* button to stop running the VI.

4.2.6. Exercises

Exercise 1: Effect of Changing Proportional Gain

0	1	2

Exercise 2: Effect of Changing Integral Gain

0	**1**	**2**

Exercise 3: Response without Anti-Windup

0	1	2

Exercise 4: Response with Anti-Windup

0	1	2

Exercise 5: Response without Set-Point Weight

0	1	2

Exercise 6: Response with Set-Point Weight

0	1	2

Exercise 7: Design PI Control according to Specifications

0	1	2

Exercise 8: PI Control Response according to Specifications

0	1	2

5. References

[1] QNET User Manual
[2] QNET Practical Control Guide