The Precision I^{2}C DAC
Rev –

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Introduction:
Radiant's I^{2}C DAC is an I^{2}C controlled, ±10V, 16-bit DAC that connects to a Precision Non-linear Materials Tester to provide additional programmable voltage sources.

Figure 1: The I^{2}C DAC Accessory

The traditional ferroelectric polarization hysteresis loop measurement requires only a single voltage stimulus output (DRIVE) and a single charge measurement input (RETURN). The measurement of multiferroic materials requires two analog stimuli applied to a sample: 1) a voltage stimulus across the sample capacitor and 2) a magnetic field within which the sample resides. Ferroelectric gate transistors require two or more

voltage sources to properly measure their performance envelopes. The I^{2}C DAC provides the extra voltages. The tester's I^{2}C bus will support up to eight devices with different addresses and each can be independently controlled from QuikLook or from within a complex Test Definition.

I^{2}C Bus

The I^{2}C 2-wire serial bus allows communications between integrated circuits. All types of IC chips now have I^{2}C communications capabilities including serial EEPROM memories, DACs, ADCs, logic latches, relay drivers, and RF communications chips. The I^{2}C bus was created by Philips Electronics (now NXP) in the 1980s. NXP maintains the standard world-wide. Information about the bus is found at www.i2c-bus.org or at http://www.nxp.com/documents/other/39340011. The standard I^{2}C bus consists of four lines. Radiant has added two extra lines to supply ±15V power to energize analog circuits driven by I^{2}C chips.

1) +15V
2) SDA   (data)
3) Power   (3.3V)
4) Ground
5) SCL   (clock)
6) -15V

The I^{2}C cable that connects the accessory to the tester is industry-standard 6-wire telephone cable with 6-pin RJ-11 connectors on either end. All I^{2}C connectors on all Radiant products have the same pin-out. This requires that the connectors on the I^{2}C cable have a 180º twist on either end. Thus, either end of the cable may be attached to either the I^{2}C DAC or the tester. Contact Radiant for assistance if you plan to build your own accessory. The cables are available from Radiant.

The I^{2}C Address

Each I^{2}C DAC can have one of eight addresses set by three jumpers on the board inside the enclosure. Note that two I^{2}C devices on the same bus *may not have the same address*.
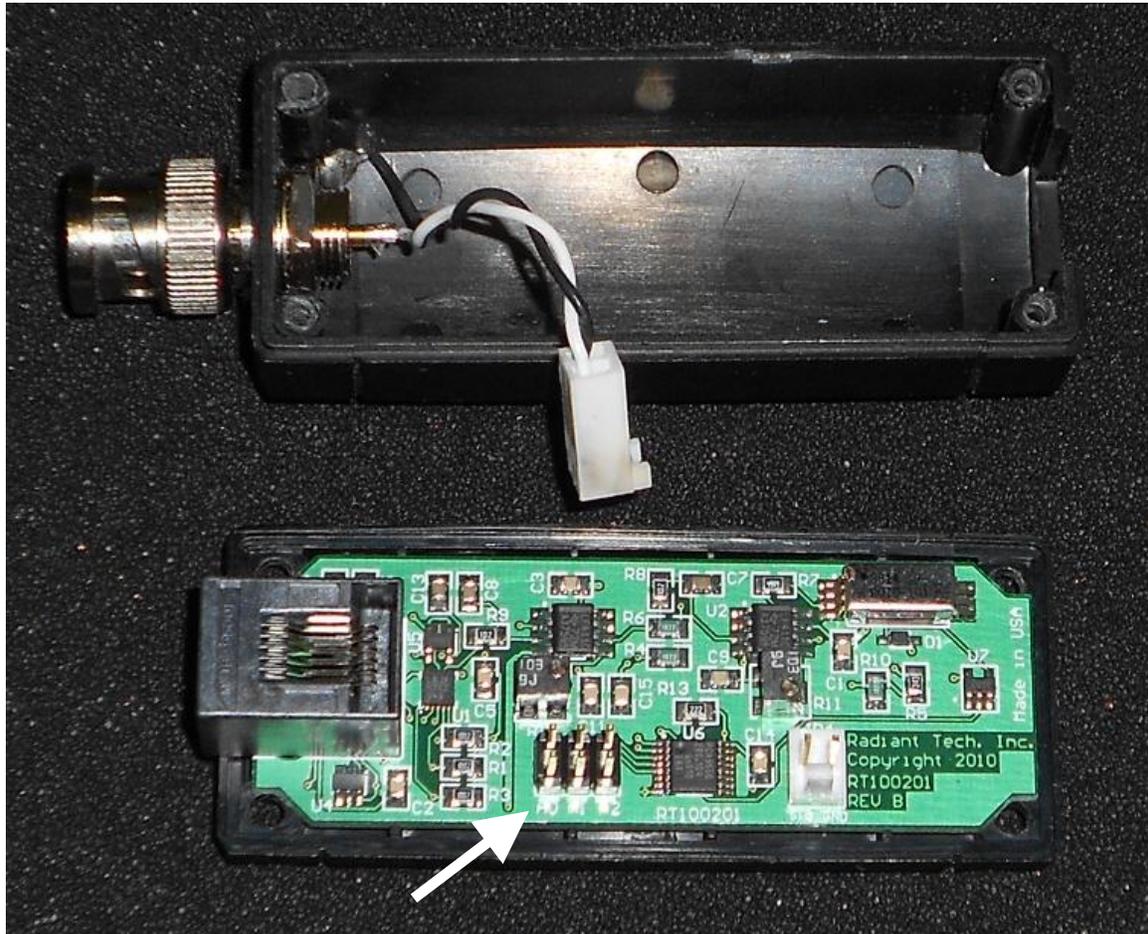
Figure 2: The I^{2}C DAC Address Pins

A jumper (also called a jam) on a pin-pair will short that address line to ground, equivalent to logic zero. The three address pins provide the eight combinations of addresses.

- 0) The address of "0" requires a jam on each address pin.
- 1) The address of "7" requires no jams on any pin.

The address pins in Figure 2 indicate address "7". It is the default setting.

Multiple I^{2}C DACs on One Tester

Every task in Vision that addresses the I^{2}C DAC has a window in which to enter the address of the targeted device. Multiple devices may be attached to the tester using a

Radiant I^2C Spider Board but care must be taken to ensure that the current capacity of the tester power supply is not exceeded. Each DAC will consume up to 24mA of ±15V. The I^2C port of each tester can support eight I^2C DACs *if there is no internal 100V or 200V amplifier* in the tester. If the tester has an internal 100V or 200V amplifier, we recommend that you connect no more than two I^2C DACs to the I^2C port. Extra DACs on the port will not damage the tester but there may be a drop in the output voltage of the DAC if the tester power supply is operating beyond its limit.

Architecture
The I^2C DAC accessory has an electromechanical relay on the output of the DAC to disconnect the DAC from the instrument being controlled. The air gap of the relay contacts will act as a 1pF series capacitor when the relay is open.
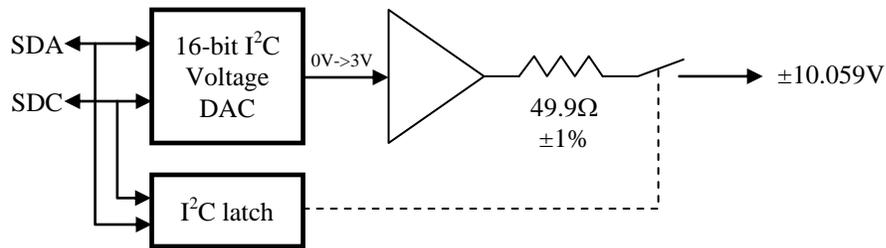

Figure 3: Architecture of the I^2C DAC

The maximum current output for the circuit is ±18mA. A dead short on the output will not damage the accessory but the output voltage will begin to drop below the voltage assigned by Vision if the output current demand exceeds 18mA.

Both of the I^2C chips in Figure 3 share the same address.

I^2C DAC Tasks
There are two tasks to control the I^2C DAC accessory directly.

I2C Relay
The I2C Relay Task opens, closes, or toggles the output relay of the accessory without changing the output voltage.
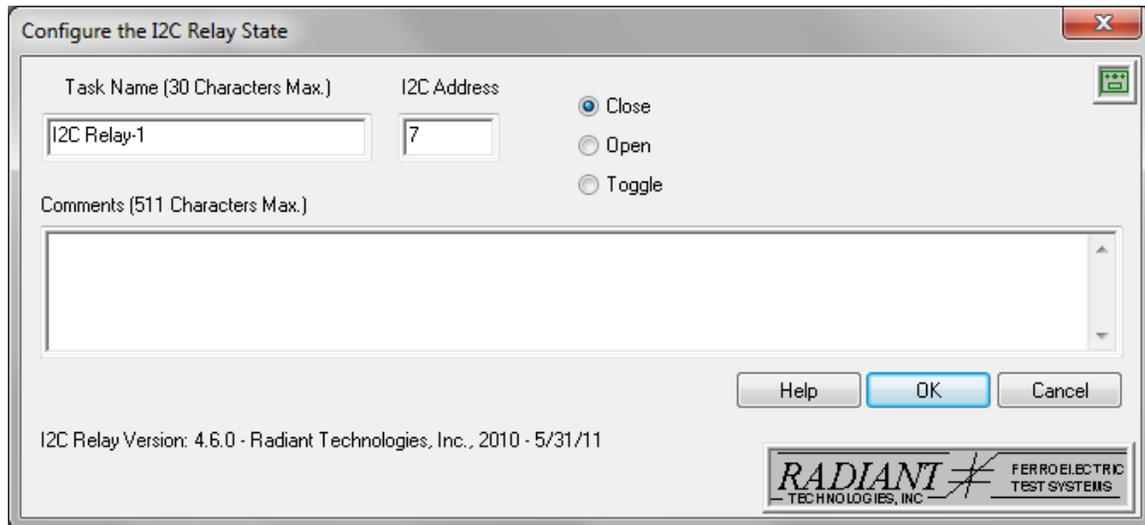
Figure 4: Menu for the I2C Relay Task

The I2C Relay Task needs two parameters: 1) the address of the accessory and 2) the desired state of the relay. The menu in Figure 4 shows Address "7" and the relay will close when the OK button is clicked. The "Toggle" option means that the relay will switch states.

I2C Volts

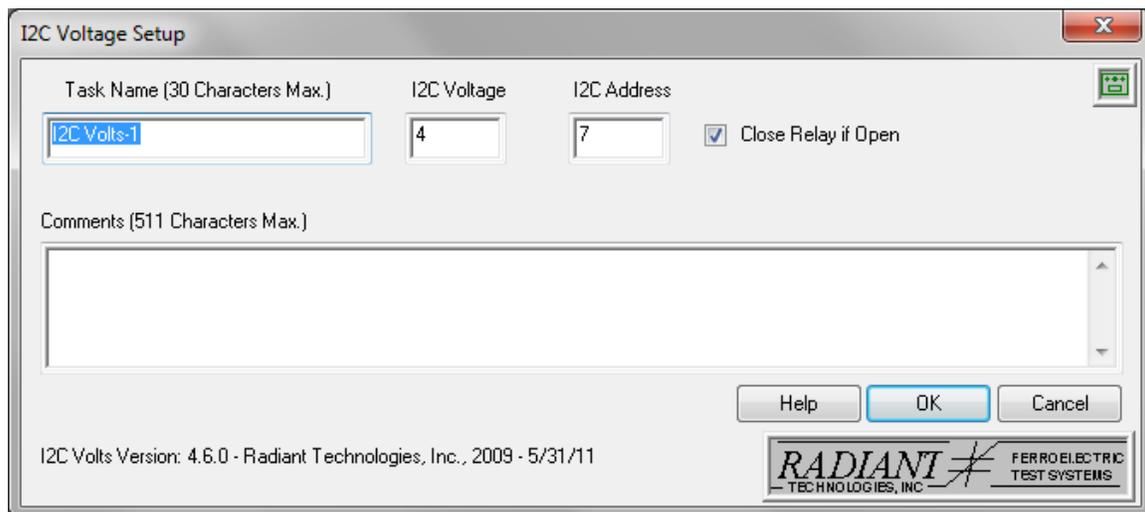The voltage output of the I^{2}C DAC accessory is set using the I2C Volts Task.

Figure 5: Menu for the I2C Volts Task

The I2C Volts Task needs three parameters: 1) the address of the device, 2) the desired output voltage (±10.059 volts), and 3) whether to close the relay after setting the voltage *if the relay is open*. If the relay is already closed when this command is executed, the "Close Relay if Open" checkbox is ignored. If the relay is open when this command is executed and the "Close Relay if Open" checkbox is not checked, the voltage output of the DAC will change to the assigned value *but the output relay will remain open.*

Read Sensor

A third task in the Vision Library that is useful in conjunction with the I^{2}C DAC accessory is the Read Sensor Task. This task measures the voltage on the assigned SENSOR input and report its value.
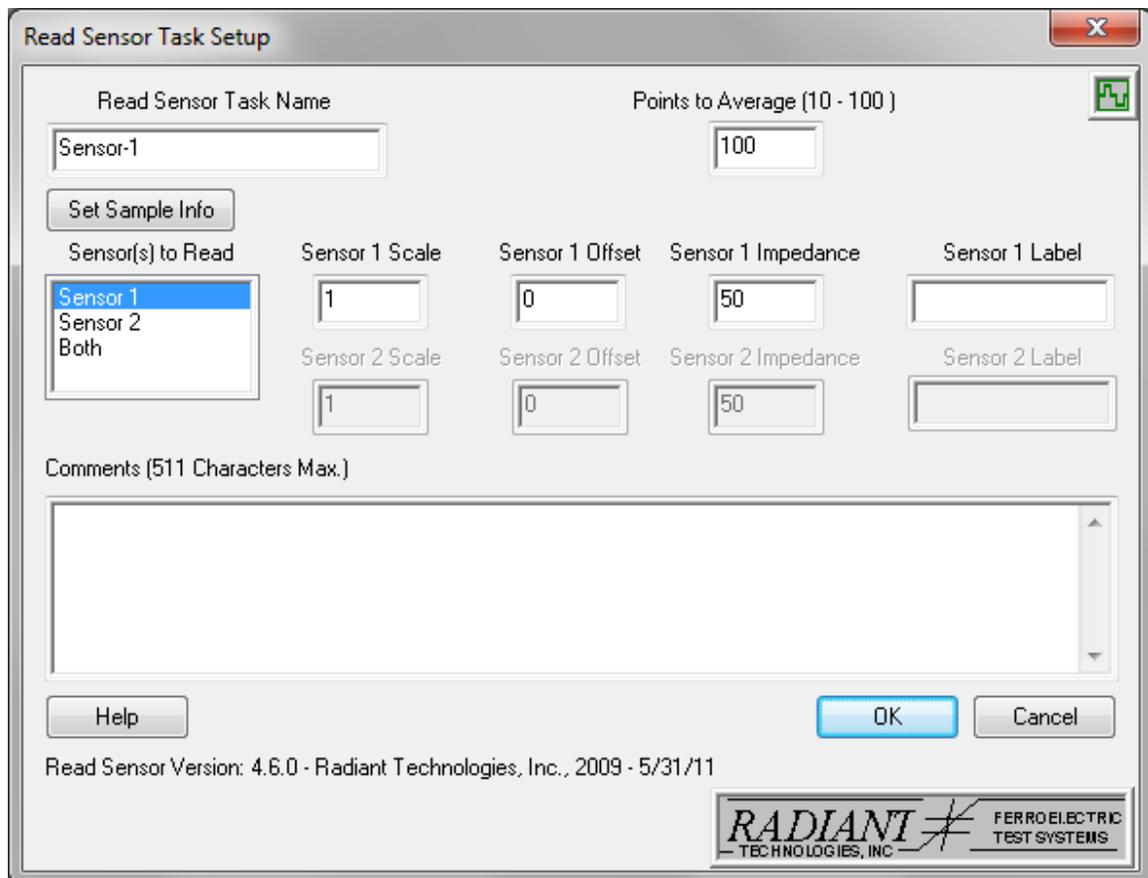

Figure 6: Menu for the Read Sensor Task

The calibration of the I²C DAC accessory may be checked by attaching the accessory to one of the SENSOR ports on the tester, assigning it a voltage, and executing the Read Sensor Task to measure the output of the DAC.

If the output of the I²C DAC accessory is run through a "T" connector to a SENSOR input, Vision can watch the output of the I²C DAC during the execution of a Test Definition. The SENSOR measurement may then update a Custom User Variable that itself can be used for plotting data during program execution. See the User Variable folder in the Program Control folder of the Vision Library.

Custom Tasks using the I²C DAC

There are presently two sets of custom tasks that use the I²C DAC accessory to control a sample during data collection.

Magnetoelectric Response Task

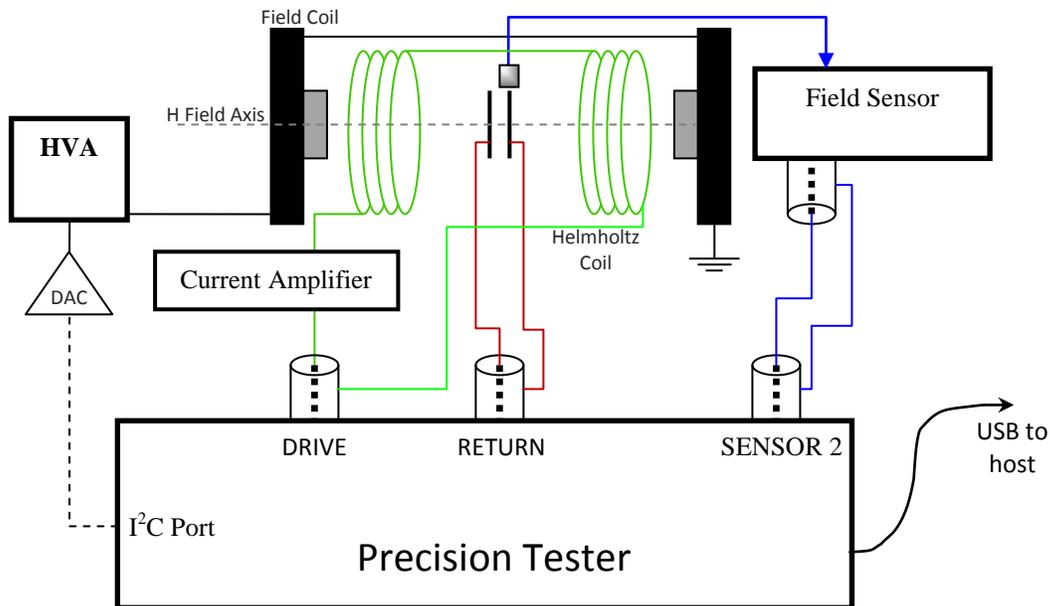The MR Task can use an I²C DAC to set a magnetic bias field across the sample during test.

Figure 7: Test Configuration for the MR Task with Magnetic Bias Field

The Field Coil in Figure 7 generates the bias field. The I²C DAC is attached to the input of the high voltage amplifier the drives the Field Coil. The controls for this configuration are on the MR Task menu.
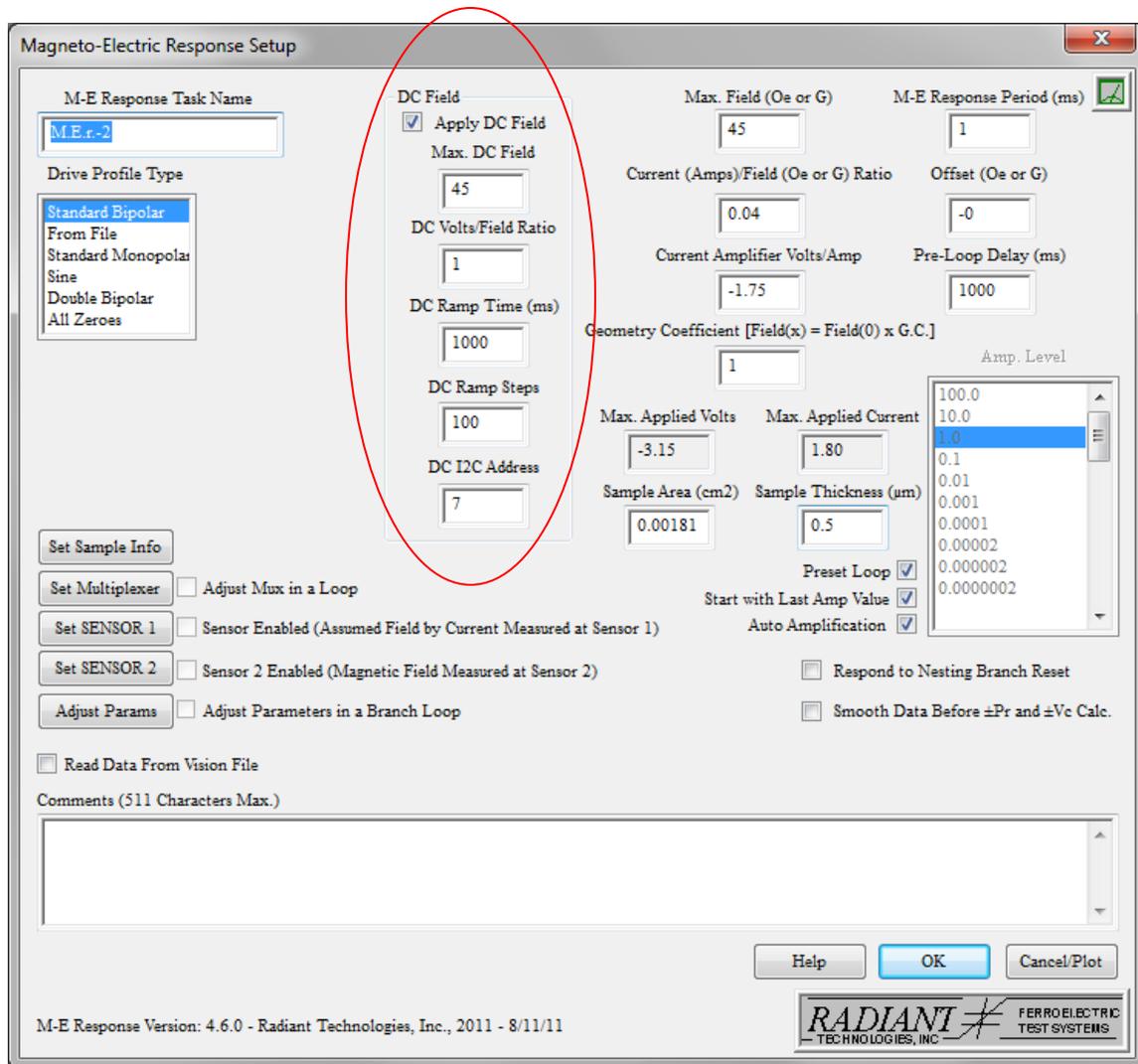
Figure 8: Menu for the MR Task

If the "DC Field" check box is checked, Vision will find the I^{2}C DAC at the address given in the "DC I2C Address" window of the menu, calculate the voltage necessary to generate the assigned magnetic field, and output that voltage to the DAC. An error will occur if the "DC Field" box is checked but no I^{2}C DAC resides at the given address.

A second magnetoelectric task in the Vision Library that uses the I^{2}C DAC is the Magneto-Bias Voltage Task.
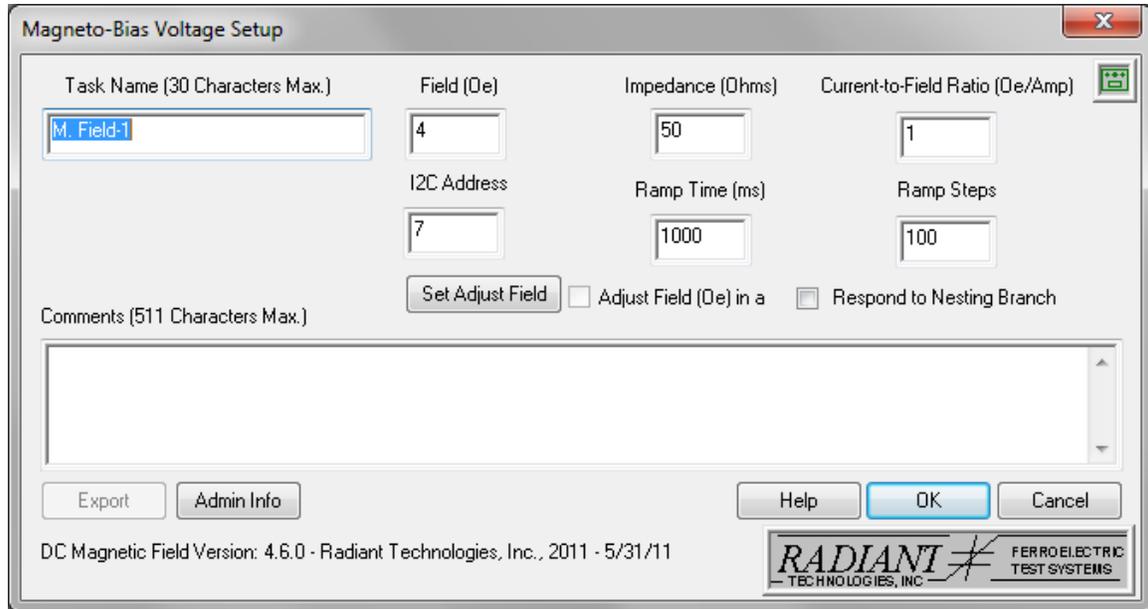
Figure 9: Menu for the Magneto-Bias Voltage Task

This task allows the user to independently control the bias magnetic field in the test setup of Figure 7. For instance, this task may be used inside a Branch Loop to step the bias magnetic field across a magnetoelectric sample while the tester collects polarization hysteresis loops.

Magnetoelectric Sample Voltage Bias

A second I^2C DAC accessory may be used during MR Task execution to apply a bias voltage across the sample during magnetic stimulation. Notice in Figure 7 that one side of the sample is grounded so the sample sees zero volts during the test. A second I^2C DAC may be attached to the sample as shown in Figure 10 so the sample can be biased with a voltage during the test.
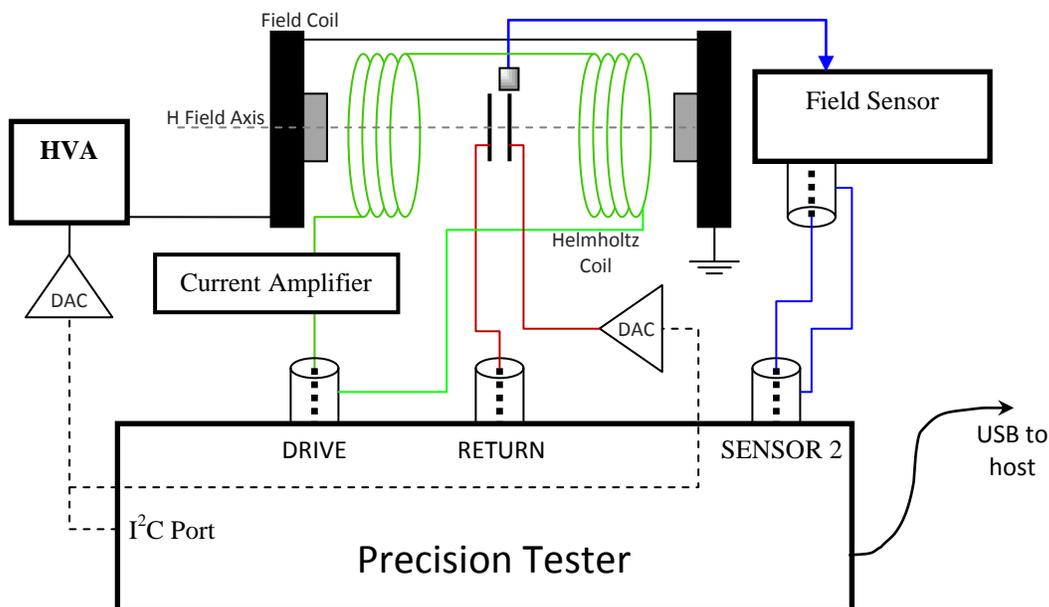
Figure 10: Test Configuration for the MR Task with Sample Voltage Bias

In this case, there will be two I^2C DAC accessories attached to the tester. The DAC establishing the magnetic bias field is controlled directly from the MR Task or the Magneto-Bias Voltage Task. The I^2C DAC applying a bias voltage to the sample must be controlled by a separate I2C Volts Task.

Transistor Measurements
Radiant offers three ferroelectric-gate transistor measurement tasks:

1. Transistor Current Task
2. Transistor I/V Task
3. Transistor Curve Trace

All three tasks require an I^2C DAC accessory to apply a bias voltage to the transistor drain while the DRIVE output stimulates the transistor gate and the RETURN input counts electrons coming from the transistor source. A second I^2C DAC may be used to bias the transistor substrate if necessary. All three transistor tasks have controls for the I^2C DAC driving the transistor drain. If a second or third DAC is added to bias the substrate or transistor tubs, they must be controlled from separate I2C Volts Tasks.

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The Tester I^{2}C Port

The I^{2}C port for the Precision Multiferroic, Precision Premier II, Precision LC, and Precision RT66B testers looks like a telephone receptacle.

Figure 11: I^{2}C port on the rear panel of a Precision Multiferroic Tester

Note in Figure 11 the blank telephone plug inside the I^{2}C port. All systems are shipped from Radiant with this blank plug inserted in the I^{2}C port. On the Multiferroic, the Premier II, and the LC, the I^{2}C port sits next to the USB socket for the tester. The USB plug will fit inside the I^{2}C port RJ11 socket. *If the tester is powered and the USB plug is accidently inserted into the I^{2}C RJ11 socket next to the USB socket, the FX2 microprocessor controlling the tester will be fatally damaged and the system will have to be returned to Radiant for repair.*

> NOTE: Always keep the blank telephone plug in the I^{2}C port when the port is not in use to prevent accidental damage to the tester.

Calibration

The output voltage of the I^{2}C DAC may be calibrated on-site using the procedures below.

1. Remove the enclosure from the I^{2}C DAC board.

2. Plug the bare board into the tester using the 6-wire telephone cable.

3. Execute I2C Volts from the QuikLook menu and have the board output zero volts with the relay closed.

4. Using a precision volt meter, measure the voltage at Point A in the image below and adjust R12 until the voltage is zero. Point A is the common point shared by R6 and R8. This node is the output of the nearby LF411A op amp.
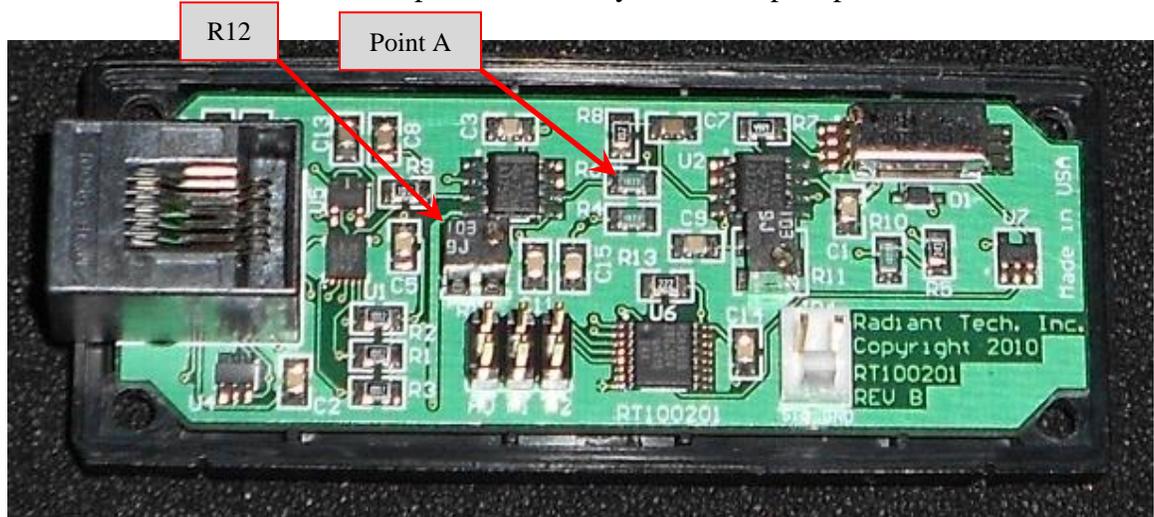
5. Attach the volt meter to the SIG pin of JP4 and adjust R11 until the voltage is zero.

6. Disconnect the DAC board from the telephone cable and reassemble the enclosure.

7. Attach the voltage meter to the output of the accessory and assign ±10.056 volts while checking the output accuracy. There is no adjustment on the accessory for range.

Rules

1. The accessory is capable of sourcing 18mA of current.

2. Vision can only update the I^2C DAC a few times per second at best. The I^2C DAC is intended for DC bias applications and waveform generation is not recommended. The I^2C DAC can be updated within Branch loops.

3. The I^2C Volts Task will change the output voltage of the DAC whether the output relay is open or closed.

   a) It will not close an open relay if the relay is open before the task executes unless told to do so.

   b) If the task is told to close the relay during execution or if the relay is already closed before execution, the relay will remain closed after the task exits.

4. The Magneto-Bias Voltage Task will automatically close the output relay during execution and the relay will remain closed after the task exits.

5. The Magnetoelectric Response Task will automatically close the relay of the I^2C DAC accessory controlling the magnetic bias field coils if the relay is open when the task starts. On completion of its execution, the task will return the relay to the state it was in prior to execution of the task.

6. The transistor tasks will all automatically close the relay of the I^2C DAC accessory controlling the transistor drain bias voltage if the relay is open when the task starts. On completion of its execution, each task will return the relay to the state it was in prior to execution of the task.

7. Always keep a blank telephone plug in the tester I^2C port when the port is not in use.

8. Never put the USB connector in the I^2C port. *Serious damage will occur*.

9. If one or more I^2C DACs are connected to the tester I^2C port when Vision starts, Vision will find them and zero their outputs.

10. An I^2C DAC may be plugged into the tester I^2C port after the tester is powered up and Vision is already started. If this is done, the output voltage of the device and the state of its relay will be unknown. The I2C Volts and I2C Relay tasks will need to be run to set the accessory to a known state.

Please contact Radiant with any questions or issues.

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