

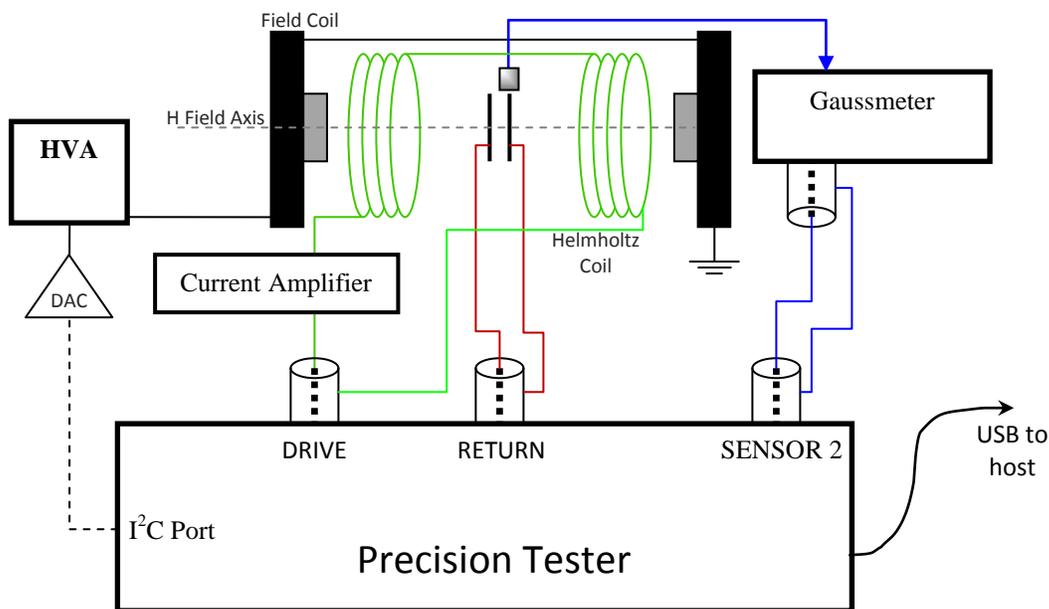
**Application Note**  
**Measuring Small Signal Capacitance vs Magnetic Field**  
**Rev A**

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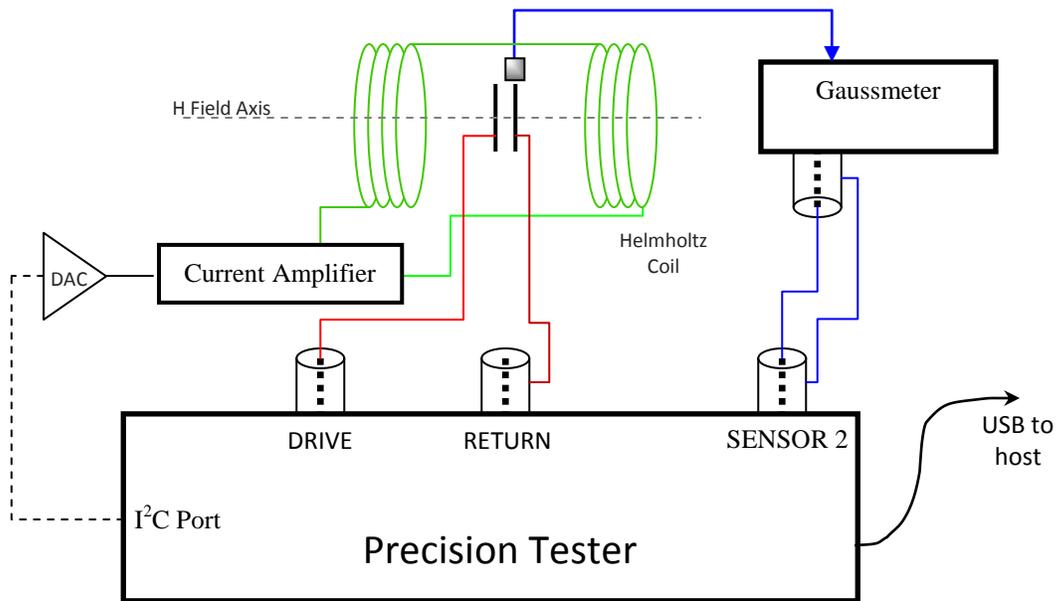
**Introduction**

The small signal capacitance of a sample as a function of applied magnetic field is easily measured in Vision. To do so requires a change to the test configuration used for the MR Task execution. The test configuration for the MR Task is shown in Figure 1 below.

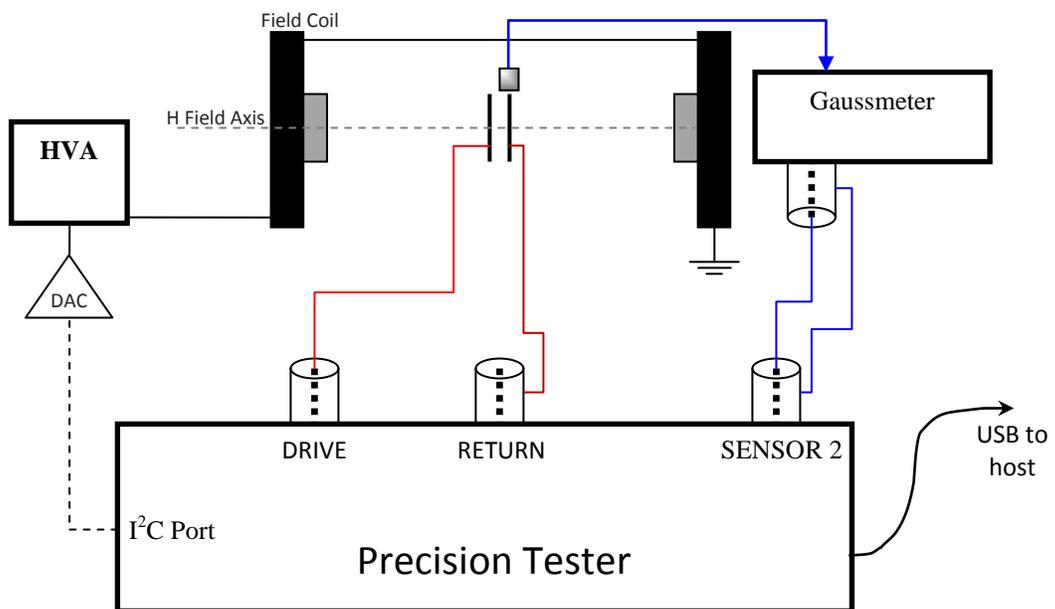


**Fig. 1:** Test configuration for using the MR Task.

The DRIVE output of the Precision tester goes into the Current Amplifier of Figure 1 to drive the Helmholtz coil. Charge generated on the sample in response to the magnetic field is captured by the RETURN input. The small signal capacitance measurement of the sample is a *voltage* measurement so the DRIVE output must be connected to the sample. Therefore, the magnetic field must be controlled using a Radiant I<sup>2</sup>C DAC voltage generator. The I<sup>2</sup>C DAC may drive either the Helmholtz coil of Figure 1 or the field coil for Figure 1. The two configurations are shown in Figures 2 and 3 below. The results will be identical. The difference between the two setups is that the Helmholtz coil will have a higher resolution in generating the magnetic field but can only go to ten's of Oersteds. The field coil will be able to go up as high as a Tesla or more.



**Fig. 2:** Measuring magneto-electric small signal capacitance vs H-field with a Helmholtz coil.



**Fig. 3:** Measuring magneto-electric small signal capacitance vs. H-field with a DC field coil.

**Theory:**

The capacitance of a magneto-electric sample must be used to convert between the charge and voltage responses of the sample when tested by the Magneto-electric Response Task. See the document “Application Note - Measuring Calibrated ME Samples with the MR Task.pdf” for this description. In summary, to compare results between the two types of test:

- 1) If the sample was *open circuit* when stimulated by the magnetic field, the voltage generated across the sample is measured, yielding  $\alpha_{ME}$ .
  - ➔ To convert to  $\alpha$ , multiply the voltage by *the small signal capacitance of the sample at that magnetic field strength* to determine the charge generated by the sample in response to the magnetic field.
  
- 2) If the sample was *short circuited* when stimulated by the magnetic field, the charge generated by the sample is measured, yielding  $\alpha$ .
  - ➔ To convert to  $\alpha_{ME}$ , divide the charge by *the small signal capacitance of the sample at that magnetic field strength* to determine the voltage that would be generated by the sample in an open circuit.

Measuring small signal capacitance is a well understood procedure that is part of the Vision test library. However, since some magnetoelectric samples change their capacitance as a function of the strength of the applied magnetic field, the small signal capacitance values used for the conversion describe above must be measured at the same magnetic field strength.

The goal of this application note is to outline the procedure for determining the capacitance of the sample at each magnetic field intensity to be seen by the sample during the execution of an MR Task. The Vision Library contains two new tasks for this purpose. The first is the DC Magnetic Field task which controls the I<sup>2</sup>C DAC in Figures 2 and 3 to generate a DC magnetic field across the sample. The second new task in the Vision Library executes a single small-signal capacitance test at a single bias voltage. The sample is connected to the tester in the standard way for small signal capacitance. The sample is placed in the active area of the magnet controlled by the I<sup>2</sup>C DAC. In a loop, the magnetic field is established by the DC Magnetic Field Task and the small signal capacitance of the sample is measured at the field strength using the Single Point CV Task.

Four legs must be executed in the Vision test definition to match the four legs of the MR Task stimulus:

- 1) Zero field to  $B_{Max}$
- 2)  $B_{Max}$  to zero field
- 3) Zero field to  $-B_{Max}$
- 4)  $-B_{Max}$  to zero field

Noise suppression is critical and the sample should be tested inside an electrical shield box. See the document “Application Note - Measuring Calibrated ME Samples with the MR Task.pdf” for a description of how to construct a suitable shield box. A sample test profile is shown in Figure 4 below.

Task V:4.7.0      12/29/11      Hardware Task      

**Task Type: DC Magnetic Field**  
**Task Name: DC Magnetic Field 1->45 Oe**  
**Field: 1.00 (Oe)**  
**Adjust Field in a Branch Loop**  
**Increment Volts By: 1.00 (Oe)**      **Branch Target**   
**Volts-to-Field Ratio (V/Oe): 0.07**  
**I2C Address: 7**  
**Ramp Time (ms): 1000.00**  
**Ramp Steps: 100**

Task V:4.7.0      12/29/11      Hardware Task      

**Task Type: Advanced C/V**  
**Task Name: Advanced CV - 0V/200mV**  
**Max. Profile Volts: 0.00**  
**Soak Delay Time (ms): 1.00e+002**  
**Pulse Count: 25**  
**Tickle Pulse Volts: 0.20**  
**Preset Pulse Volts: 0.00**  
**Preset Pulse Width (ms): 1.00**  
**Points: 1**  
**Profile: Unswitched Linear**      **Filter Target** 

Task V:4.7.0      12/29/11      Filter Task      

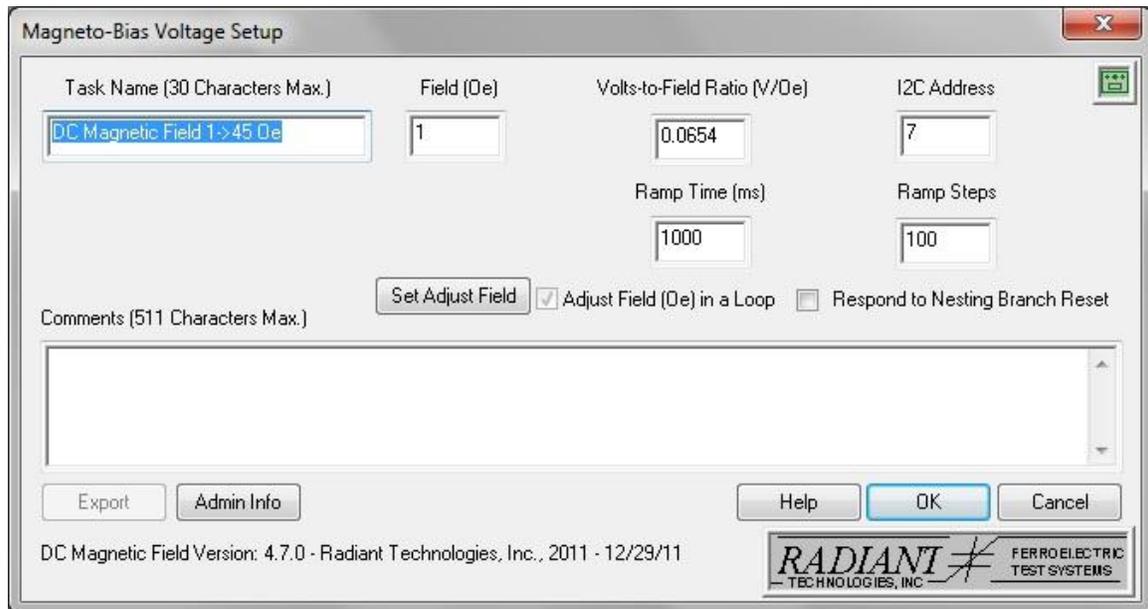
**Task Type: Single-Point Filter**  
**Task Name: Plot Cap vs H-field**  
**Input Task Type: Advanced C/V Task**  
**X-Axis: User Variable DC Magnetic Field: Current Field**  
**Captured Parameters: 1**  
**Measured Parameter 1: Capacitance (nF) at Pos.-Going Zero Volts**  
**Number of Associated Tasks: 1**  
**Input Task Names...**  
**Task 1: Advanced CV - 0V/200mV**

Task V:4.7.0      12/29/11      Branch Task      

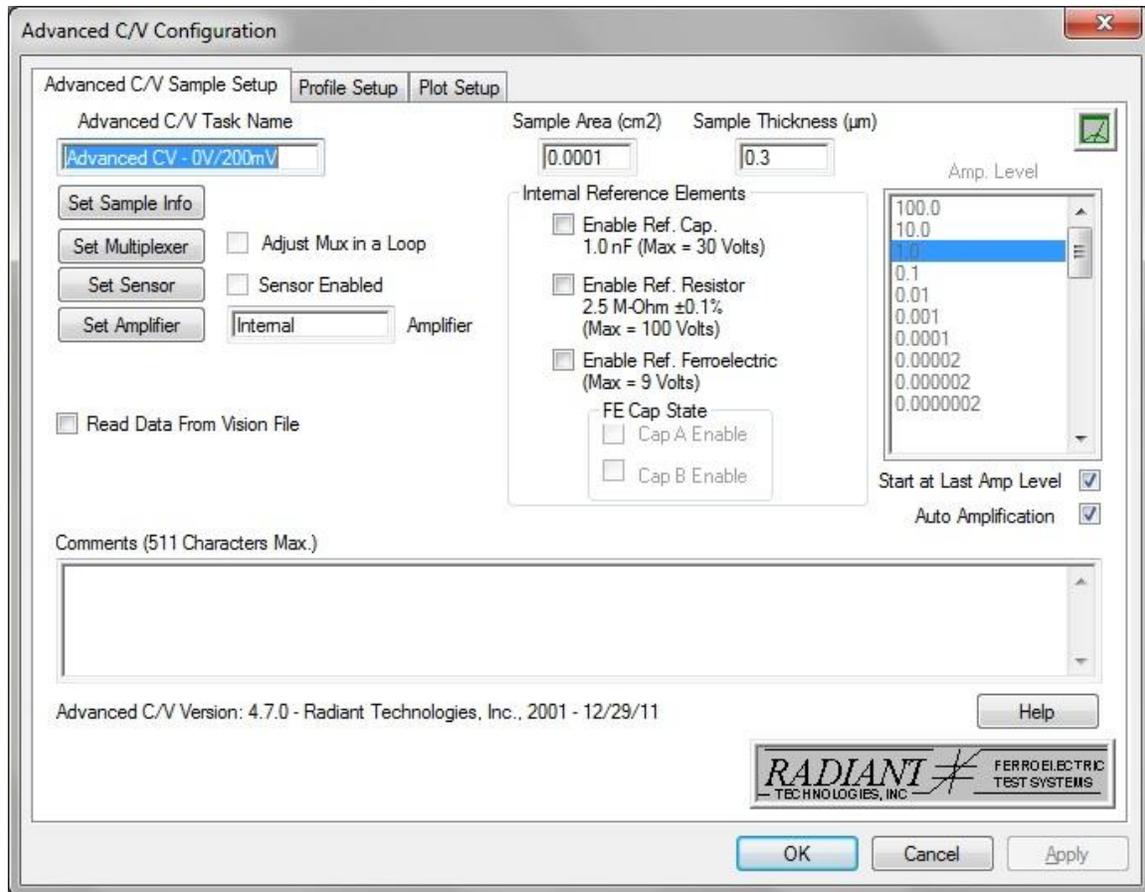
**Task Type: Branch Task**  
**Task Name: Loop to 45 Oe**  
**Logic: if DC Magnetic Field: Current Field < 45, then Branch**  
**Target Task: DC Magnetic Field 1->45 Oe**

Figure 4: Capacitance vs H-field Test Definition.

The setup menus for the two Tasks in the test definition are shown in the next two figures.



**Figure 5:** DC Magnetic Field Task menu



**Figure 6:** Advanced CV menu.

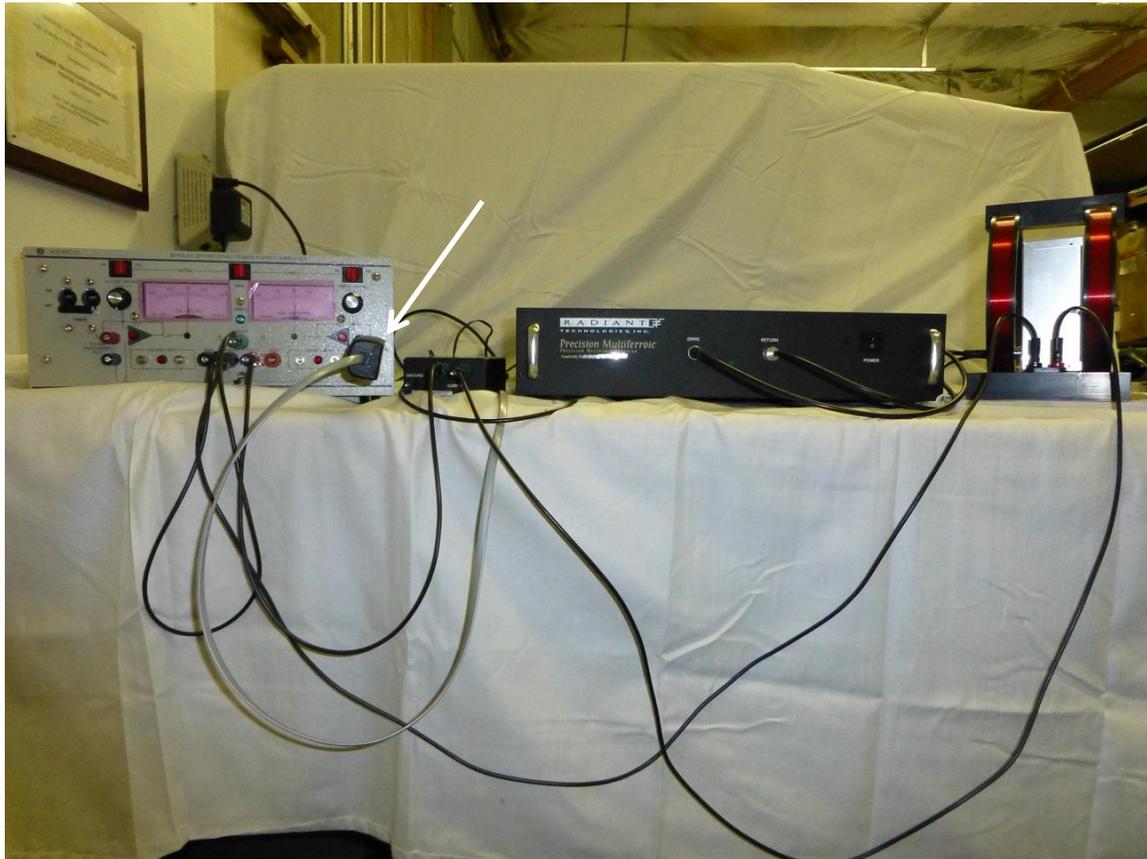
The output of the test definition in Figure 4 should be a Single Point Filter plot of the small signal capacitance of the sample as a function of the magnetic field applied across the sample.

**Calibrating the Magnetic Field:**

The magnetic field measurement by the tester should be calibrated prior to executing the small signal capacitance vs. magnetic field test. See the application note from Radiant Technologies named “Application Note - Calibrating the Magnetic Field for ME Testing.pdf”. Please review it carefully before conducting the test in order to minimize error in the magnitude of the magnetic field.

**Results:**

A photograph of the test configuration, including a shield box for the sample is shown in Figure 7.

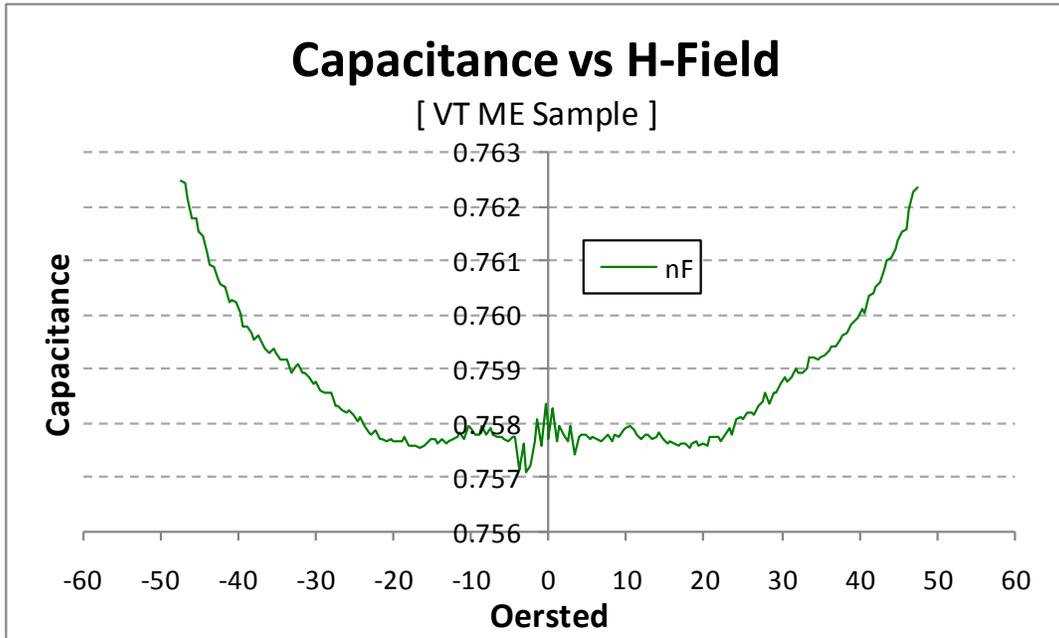


**Figure 7:** The test configuration.

The Helmholtz coil is a Lakeshore MH-6 with a 6 inch diameter. The current amplifier is a Kepco 36-6 unit capable of 36 amps up to 20 volts. The Gaussmeter is a Lakeshore Model 425 with a Hall Effect sensor. The current sensor in-line with the Helmholtz coil is a Radiant RCSH which uses an internal Hall-effect sensor to measure the current. Because of its internal Hall-effect sensor, the RCSH must be placed away from the Helmholtz coil during measurements. As an alternative, the Radiant RCSi current sensor uses an instrumentation amplifier to measure the current. It has more resolution than the RCSH but is only isolated to 200V while the RCSH is isolated to 1500V.

This sample for this experiment was a “composite” magneto-electric sample physically attaching a ferromagnetic material to a piezoelectric ceramic. It was supplied by Su Chul Yang and Shashaank Gupta of the Center for Energy Harvesting and Material Systems at Virginia Tech. A magnetic field applies a force to the ferromagnetic material which in turn creates stress changes in the piezoelectric material to which it is bonded. Although it is physically different than a true multiferroic material, the outcome is the same: an applied magnetic field creates a voltage across the sample or charge flow from the sample.

Note the Radiant I<sup>2</sup>C DAC on the input to the Kepco current amplifier and the I<sup>2</sup>C cable coming from the tester to the DAC. This connection allows Vision to set a DC current output from the Kepco.



**Figure 8:** Sample Capacitance vs. Applied Magnetic Field.

The change in small signal capacitance of the sample over the range of

**Conclusion:**

The measured points of the trace in Figure 10 may be exported and used as a template to convert between  $\alpha$  and  $\alpha_{ME}$ . See the application note “Measuring Calibrated ME Samples with the MR Task.pdf” for more information on the magneto-electric response of the Virginia Tech sample shown in Figure 8.