

# A Discrete Ferroelectric Memory using an Arduino Uno Microprocessor

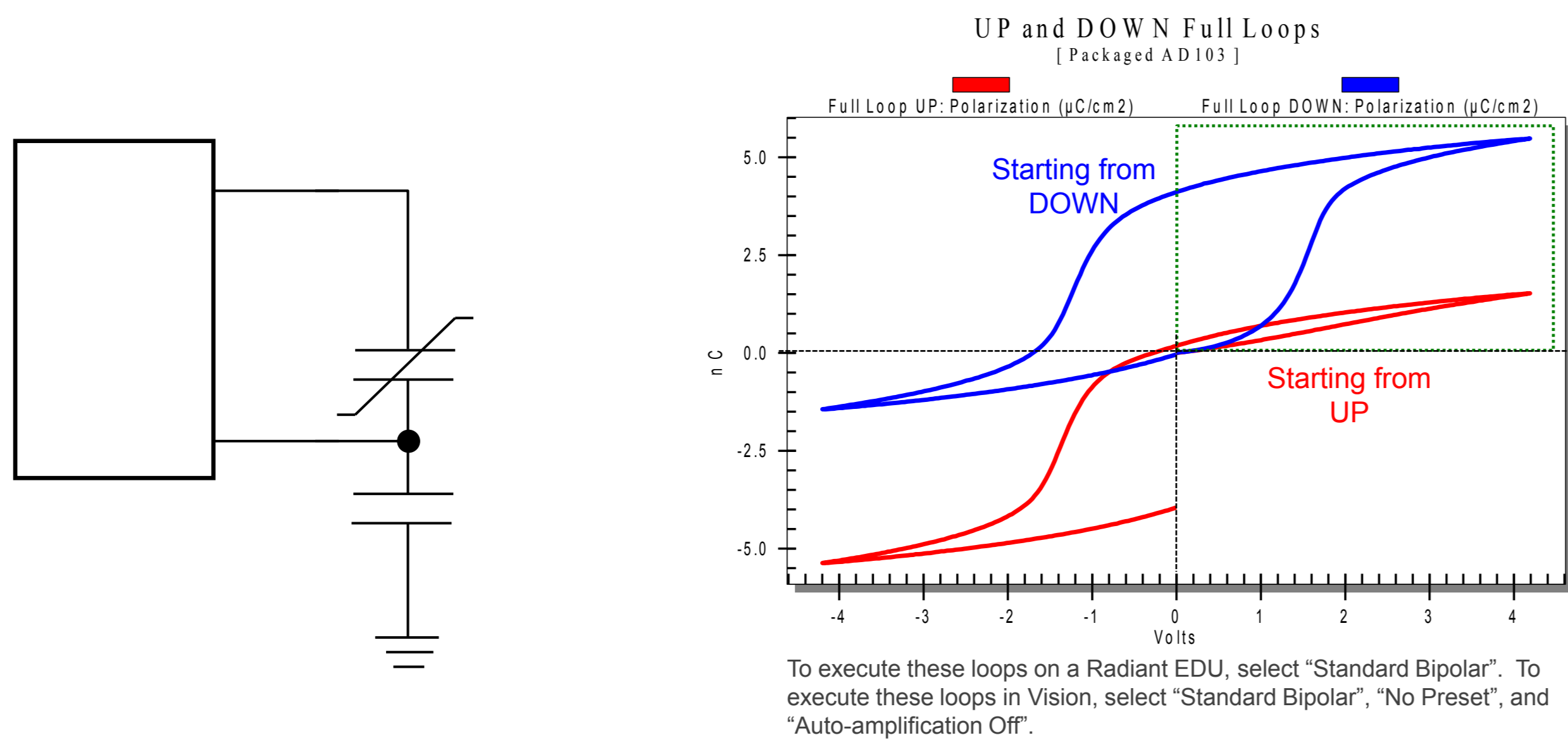
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## Introduction

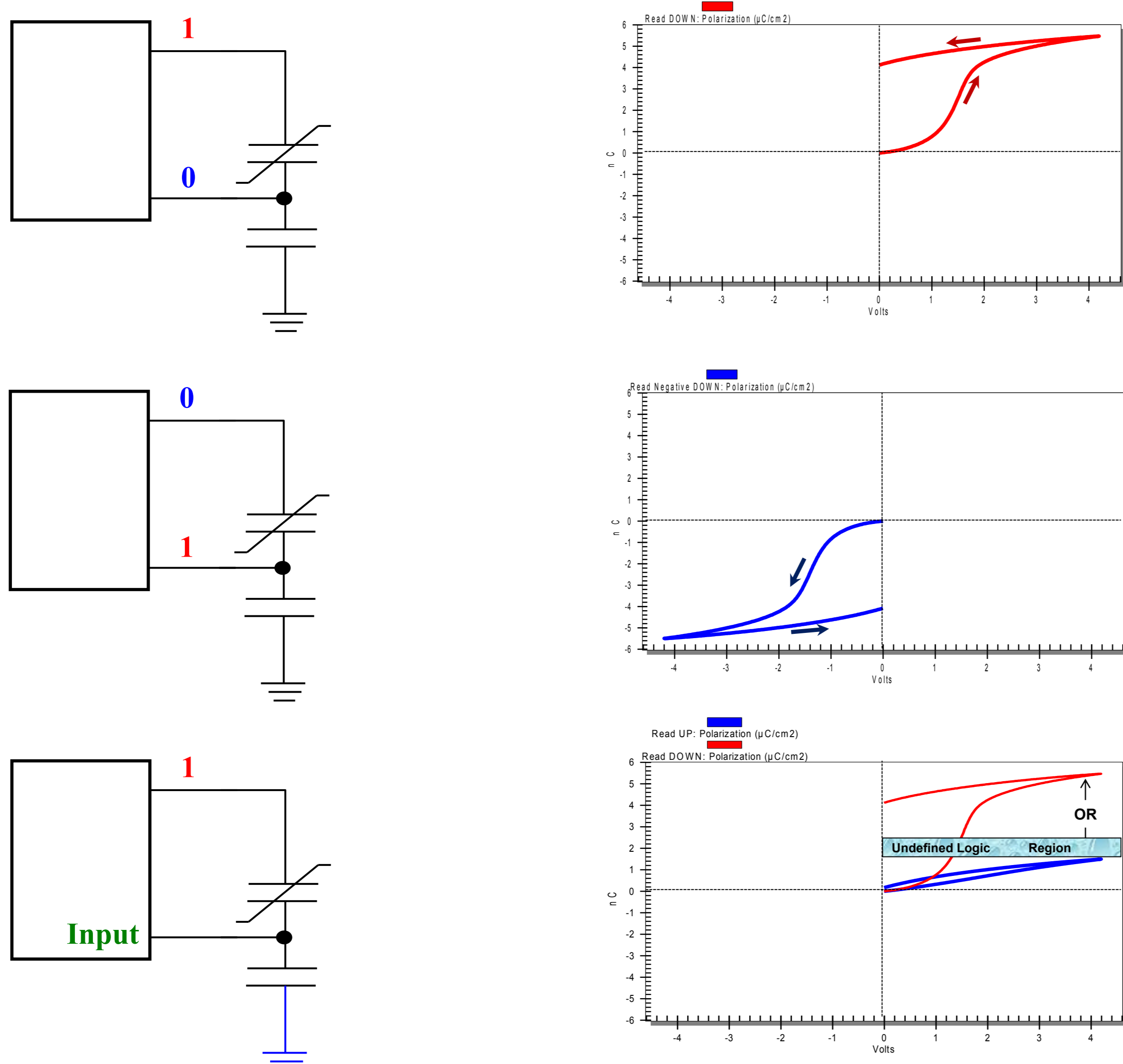
A ferroelectric capacitor exhibits remanent polarization allowing it to be used as a non-volatile memory. The charged state of the crystal lattice of a ferroelectric capacitor is a *natural* characteristic of the material. It need only be pointed in the desired direction by the application of the appropriate voltage. A ferroelectric capacitor *maintains memory* without support from a battery or the environmental protection of a package. A package is needed only to facilitate handling.

Non-volatile memory based on ferroelectricity is *charge-based*. Its state is destructively read by counting electrons coming from the capacitor when it is forced into a known direction. Ferroelectric hysteresis is typically shown as a full loop, implying continuity. Memory is *intrinsically discontinuous!*

The charge coming from a ferroelectric capacitor is most easily converted to a voltage by a linear capacitor in series with the ferroelectric capacitor, hence the Sawyer-Tower circuit [1]. Taking advantage of the unique property of microprocessor pins whereby they can act either as *active outputs* or as *high impedance level-sensing inputs*, a ferroelectric memory bit may be created by connecting a Sawyer-Tower circuit to two I/O pins of a microprocessor.



Write a datum by setting a 1:0 combination on the two I/O pins. Read the datum by setting as an input the I/O pin connected to the sense capacitor of the Sawyer Tower circuit and then applying 5V to the pin connected to the top of the circuit. Proper selection of the sense capacitor causes the sense capacitor voltage to be below the threshold for logic zero or above the threshold for logic 1.



To execute these half-loops on a Radiant EDU, select "Standard Monopolar". To execute these loops in Vision, select "Standard Monopolar", "No Preset", and "Auto-amplification Off".

## Microprocessors

The Arduino® Uno microprocessor ([www.arduino.cc](http://www.arduino.cc)) can be configured to work with the Type AD ferroelectric capacitor as a memory bit. This microprocessor is available from a variety of sources including Radio Shack. It is inexpensive, has 5 volt I/O pins, and is easy to program from any PC by USB connection. The write and read operations consist of setting the I/O pins in the proper order:

```

Write UP
// define pins
int C_Fe = 3; // use pin 3 as voltage on C_FE
int C_Sense = 2; // use pin 2 as voltage on C_Sense

// the setup routine runs when you press reset:
void setup() {
// initial pin voltage conditions...both low
digitalWrite(C_Fe, LOW); // initial condition LOW
digitalWrite(C_Sense, LOW); // initial condition LOW

// initial pin drive conditions...both output
pinMode(C_Fe, OUTPUT);
pinMode(C_Sense, OUTPUT);

digitalWrite(C_Fe, HIGH); // HIGH on C_Fe
delay(1); // 1 ms delay
digitalWrite(C_Fe, LOW); // LOW on C_Fe

// Retain with pins as inputs
pinMode(C_Fe, INPUT);
pinMode(C_Sense, INPUT);
}
void loop() {}

Write DOWN
// define pins
int C_Fe = 3; // use pin 3 as voltage on C_FE
int C_Sense = 2; // use pin 2 as voltage on C_Sense

// the setup routine runs when you press reset:
void setup() {
// initial pin voltage conditions...both low
digitalWrite(C_Fe, LOW); // initial condition LOW
digitalWrite(C_Sense, LOW); // initial condition LOW

// initial pin drive conditions...both output
pinMode(C_Fe, OUTPUT);
pinMode(C_Sense, OUTPUT);

digitalWrite(C_Sense, HIGH); // HIGH on C_Sense
delay(1); // 1 ms delay
digitalWrite(C_Sense, LOW); // LOW on C_Sense

// Retain with pins as inputs
pinMode(C_Fe, INPUT);
pinMode(C_Sense, INPUT);
}
void loop() {}
    
```

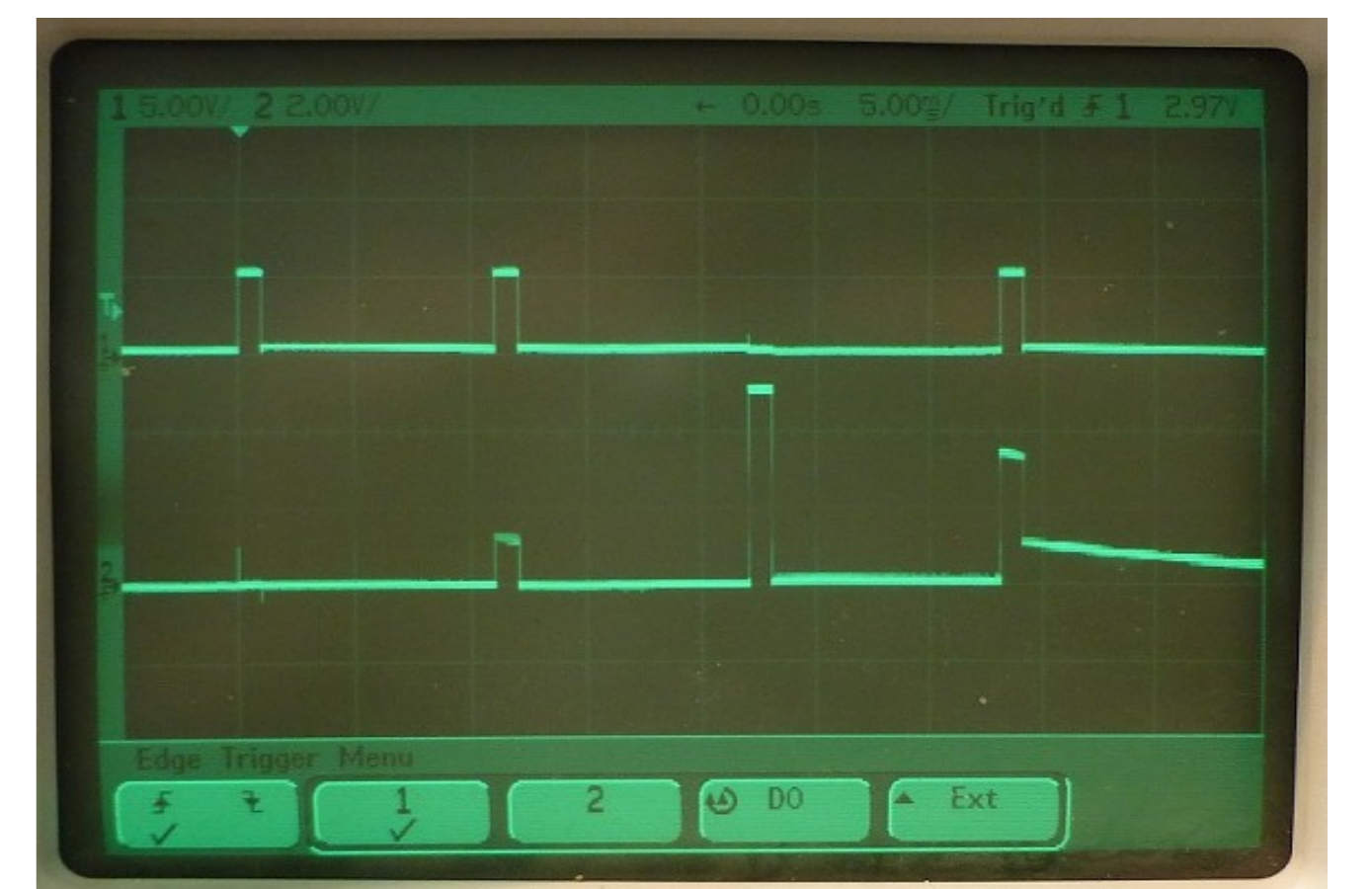
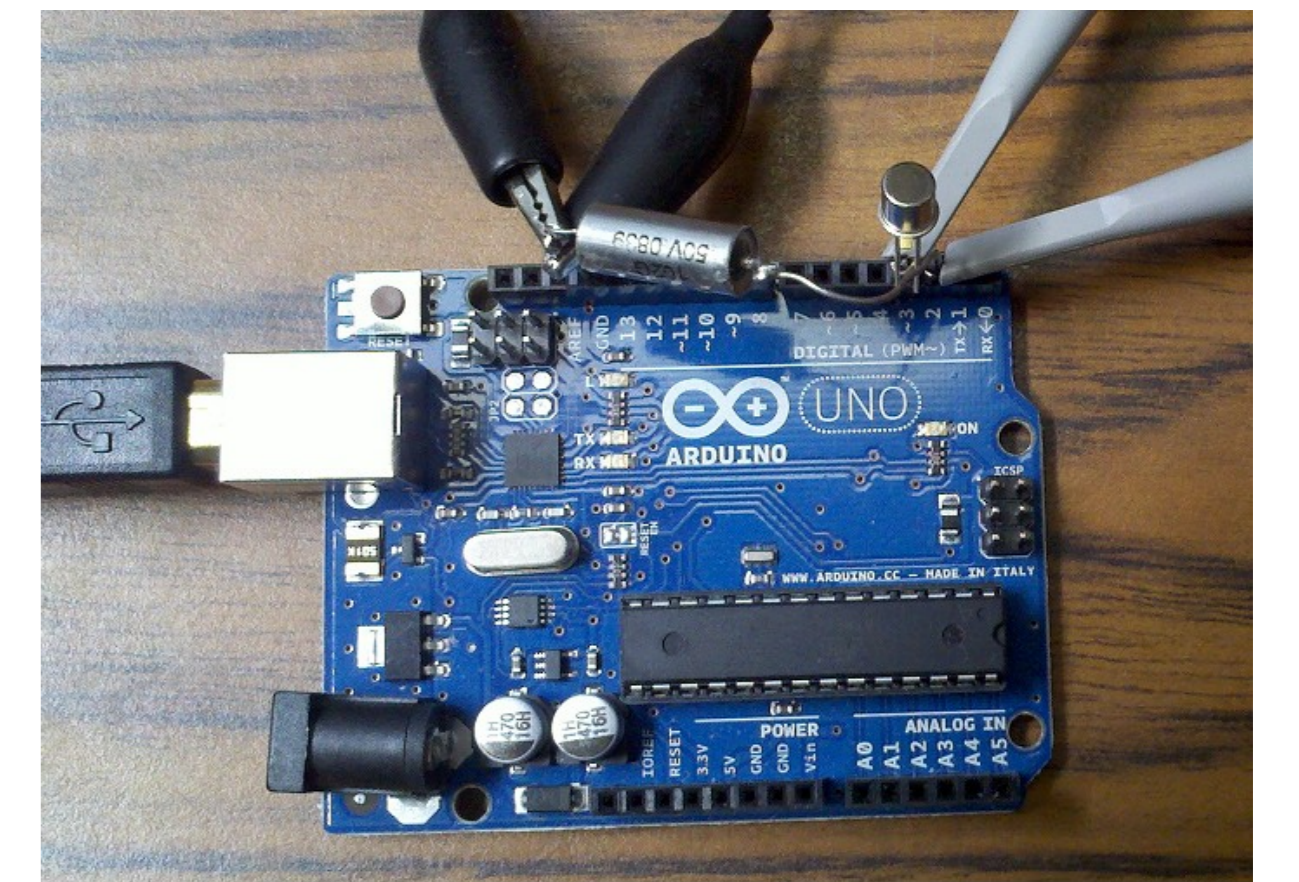
```

Read
// Read
// define pins
int C_Fe = 3; // use pin 3 as voltage on C_FE
int C_Sense = 2; // use pin 2 as voltage on C_Sense
int FeCap = 0; // storage for FeCap read value
int ledPin = 13; // arduino LED connected to pin 13

// the setup routine runs once when you press reset:
void setup() {
// initial pin drive conditions...both input
pinMode(C_Fe, INPUT);
pinMode(C_Sense, INPUT);
pinMode(ledPin, OUTPUT); // use Arduino LED to display state

// initial pin voltage conditions...all LOW
// these voltages will not output until pin is configured as output
digitalWrite(ledPin, LOW); // low on LED pin
digitalWrite(C_Fe, LOW); // initial condition LOW
digitalWrite(C_Sense, LOW); // initial condition LOW

// perform the read
pinMode(C_Fe, OUTPUT); // set C_Fe pin as output...still LOW
digitalWrite(C_Fe, HIGH); // set C_Fe pin HIGH
FeCap = digitalRead(C_Sense); // read the sense capacitor
delay(1); // 1ms delay to shape oscilloscope image
digitalWrite(C_Fe, LOW); // set C_Fe pin back LOW -- default state
pinMode(C_Fe, INPUT); // set C_Fe pin to input -- default state
digitalWrite(ledPin, FeCap); // use LED to indicate FeCap State
}
void loop() {}
    
```

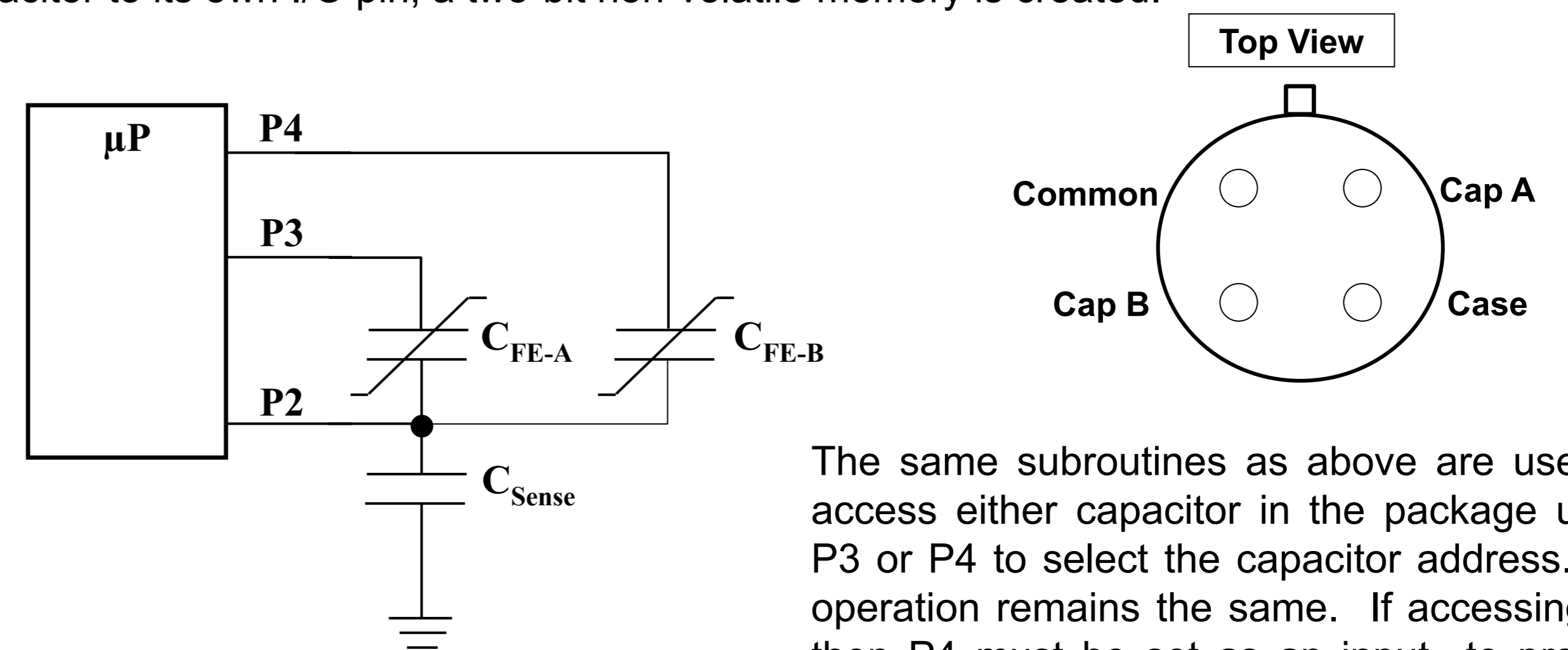


## Capacitor Properties

The circuit operation shown in the oscilloscope image above was achieved using a capacitor with 10,000 square microns of area (AD103) and a 1nF sense capacitor. For detailed information on how to select the sense capacitor and mathematically determine circuit performance, go to [www.ferroemems.com](http://www.ferroemems.com) and click on the link for "Introduction to the FeMem". For information on long term reliability, click on the link "Ferroelectric Capacitor Properties".

## Two Bits instead of One

The Type AD capacitor package contains two identical capacitors. By connecting the second capacitor to its own I/O pin, a two-bit non-volatile memory is created.



The same subroutines as above are used to access either capacitor in the package using P3 or P4 to select the capacitor address. P2 operation remains the same. If accessing P3 then P4 must be set as an input to prevent voltage application across the P4 capacitor from the P2 node. If accessing P4 then P3 must be set as an input.

## References:

<sup>1</sup> C. Sawyer and C. Tower, Rochelle Salt as a Dielectric, Phys. Rev, vol 35, Feb 1930, p. 269