Ferroelectric Event Detector

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What is the Opportunity?

All integrated circuits are deaf, dumb, and almost blind.

*Ferroelectric capacitors can see the world.*

Combining ferroelectric capacitors with transistor technology allows functionality orthogonal to anything yet imagined.

This presentation describes some possibilities.
Introduction

Unlike CMOS, ferroelectric capacitors in the outside world do not *burn up* from static discharge, *lock up* due to photonic impingement, or *die* from contamination.

Proposal: Have a sensor switch a ferroelectric capacitor then read that capacitor like a memory bit.
The $R_{FE}C$ Circuit

First, we need to understand how a ferroelectric capacitor interacts with a series resistor.

We must go from:

$$V_{out}$$

to:

$$V_{out}$$
Classic RC

\[ V_{out} = V_{pwr} \cdot (1 - e^{\frac{-t}{RC}}) \]

- \( C = 100\text{pF} \& 1\text{nF} \)
- \( R = 15\text{M} \Omega \)

Numerical Solution
Ferroelectric Capacitor

What is the capacitance of a ferroelectric capacitor?

Take the derivative of the polarization hysteresis loop!

Autonomous Memory
Ferroelectric Capacitor Model

For a simple model, create a 2-level capacitor to represent the ferroelectric capacitor \textit{when it switches}.

Use only \textit{Cap 1} for \textit{all voltages} when the capacitor does not switch.

Use \textit{Cap 2} only when the capacitor switches.
Numerical Solution

Switching $C_{FE} = \text{Use higher capacitance from 2.2 to 2.9 volts.}$

$R = 15\text{M}\Omega$

$$V_{out} = V_{pwr} \cdot (1 - e^{-\frac{t}{RC_{FE}}})$$
A Real $RC_{FE}$

Measured

$C = 400 \, \mu m^2$ 2600Å-thick 20/80 PZT
$R = 15 M\Omega$

Defined as the “Shelf Voltage”.

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Add a Transistor

A transistor added to the $R_{C_{FE}}$ circuits causes negative feedback to $V_{out}$.
Add a Transistor

If current through both Rs is the same, then

1) All of the current in the $R C_{FE}$ circuit goes into the capacitor.

2) Most of the current in the transistor circuit goes through the transistor so much less goes through the capacitor.

The ferroelectric capacitor in the transistor circuit must charge more slowly!
$RC_{FE}$ vs $RC_{FE}X$

Measured

$C = 400 \mu m^2$ 2600Å-thick 20/80 PZT
$R = 15M\Omega$
$\beta = 2$

$V_{out} = V_{pwr} \cdot (1 - e^{(1+gain)RC_{FE}})$

Blue dashed = $RC_{FE}$

Red solid = $(1+gain)RC_{FE}$

With no transistor, gain = 0 and the classic equation emerges.

$V_{threshold}$ for the transistor causes this gap.

$(1+\beta) = 3$
Event Detector

Autonomous Memory

Logic Buffer

R\text{Sense}

C_{FE}

R_{in}

V_{pwr}

T1

T2

R_{out}

Logic Out

Event Sensor

Explanation on the next page!
Event Sensor powers this node high which turns on T1 and switches $C_{FE}$ DOWN through T1 to ground.

Diode blocks negative voltages that can occur from some sensors like piezoelectric switches.

$R_{in}$ is necessary because T1 is a FET with no gate-to-source current path. T1 is a FET to minimize current requirements from the Event Sensor.

$T2$ is ON if there is voltage across $R_{sense}$, $T2$ is OFF if no voltage across $R_{sense}$.

Logic Out is High if $T2$ is ON and LOW if $T2$ is OFF.
After Vpwr activates the circuit, C_FE is always UP.
Event Sensor forces $C_{FE}$ DOWN *only* if event occurs.
Vpwr reads $C_{FE}$.

Does the shelf voltage occur?

T2 turns ON if the shelf voltage occurs.
Signal Interpretation

Every time \textit{Vpwr} is applied, the ferroelectric capacitor is left in the \textit{UP direction}. Every read is a \textit{Reset}.

The ferroelectric capacitor can only be set \textit{DOWN} by an \textit{Event}.

Every time the circuit is powered up, a read takes place:

\begin{itemize}
  \item \textbf{If the shelf voltage occurs}, the ferroelectric capacitor was \textit{DOWN} before \textit{Vpwr} was applied. \textit{An event occurred since the last read operation.}
  \item \textbf{If the shelf voltage does not occur}, then the ferroelectric capacitor was \textit{UP} before \textit{Vpwr} was applied. \textit{An event did not occur since the last read operation.}
\end{itemize}
Output Buffer Operation

When \( V_{pwr} \) steps to the power voltage, \( T_2 \) turns on until \( A \) approaches to \( V_{\text{Threshold}} \) of \( V_{pwr} \). See the area in the plot with the blue arrows.

The microprocessor powers the circuit with an I/O pin and reads the circuit output with another.
Output Buffer Operation

The *switching* trajectory causes *Logic Out* to go HIGH for much longer than the non-switching trajectory.

Programming is simple: output HIGH here and read here.
Autonomous Event Detector

Event Input Line
Ferroelectric Capacitor
Input Overvoltage Protection

Autonomous Memory
Output Buffer
WRITE DOWN
Bend piezoelectric detector
OR
Place cell phone near antenna with NFC radio active.

READ:
1. Press **ON**.
2. The **RED** LED will always light indicating power.
3. The **GREEN** LED will light if event did not occur.
This piezoelectric flapper is a Measurement Specialties, Inc. LDT0-28K Piezo Film Sensor. Bent 90 degrees, it generates exactly 7nC of charge, precisely the amount required to saturate one of Radiant’s Type AB 20/80 PZT or Type AD 3/20/80 PNZT thin film capacitors.

The Radiant ferroelectric capacitor is encased in the TO-18 transistor package on the Event Detector board.
All new phones have Near Field Communications capability. It is probably labeled as Smart Tag or a financial transaction application.

Turning on the NFC app and waving the phone over the antenna will write the ferroelectric capacitor!
Possibilities

- An event detector can monitor the security of a door when power to a security system fails.

- How many server enclosures are there in the world?
Only slight modifications are need to implement event detectors.
Possibility

Event Detectors embedded in an RFID Tag report earlier events when powered by an RF reader:

Piezoelectric Bender
PV Sensor
pMEMs Shock Detector
Radiation Detector
SOC
RF XCVR
Small cheap µP
EDs
Possibility

A wearable RFID Security Badge that communicates between its user and the security system:

Piezoelectric Key Pad

RF XCVR

Small µP

4 EDs
Possibility

A super-fast system-wide fault recorder: subsystems write to their local ED register if a fault occurs. Processor surveys ED registers on reset.
Radiation spectroscopy: Use ferroelectric capacitors of different thickness and area to differentiate the *energy content* of a solar storm affecting a satellite. EDs record storm intensity while the satellite is shut down due to the storm.
Fabrication

Autonomous memory and autonomous event detectors can be constructed using *any* technology:

- Discrete or Integrated Bipolar
- Discrete FETs
- CMOS
  - Integrated FRAM process
  - Bump bonding of the capacitor to the CMOS die.
- JFETs
- Integrated-scale Mechanical Relays
- Thin-Ferroelectric-Film FETs. (*This has been done at Radiant!*)

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Closing

We at Radiant believe that integrated ferroelectric capacitors will have their greatest impact following a path completely different than what has been known in the past.
See:

*Nuts & Volts Magazine*

“A Simple Ferroelectric Memory”

*February 2015 Issue*