FERROELECTRIC FIELD-EFFECT TRANSISTOR DIFFERENTIAL AMPLIFIER CIRCUIT ANALYSIS

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ABSTRACT

There has been considerable research investigating the Ferroelectric Field-Effect Transistor (FeFET) in memory circuits. However, very little research has been performed in applying the FeFET to analog circuits. This paper investigates the use of FeFETs in a common analog circuit, the differential amplifier. The two input Metal-Oxide-Semiconductor (MOS) transistors in a general MOS differential amplifier circuit are replaced with FeFETs. Resistors are used in place of the other three MOS transistors. The FeFET model used in the analysis has been previously reported and was based on experimental device data. Because of the FeFET hysteresis, the FeFET differential amplifier has four different operating modes depending on whether the FeFETs are positively or negatively polarized. The FeFET differential amplifier operation in the different modes was analyzed by calculating the amplifier voltage transfer and gain characteristics shown in figures 2 through 5. Comparisons were made between the FeFET differential amplifier and the standard MOS differential amplifier. Possible applications and benefits of the FeFET differential amplifier are discussed.

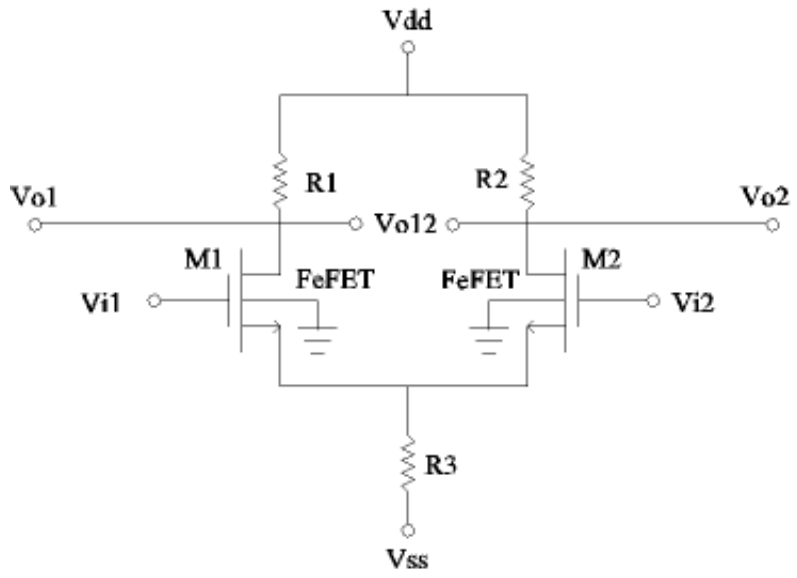

Figure 1: FeFET Differential Amplifier Circuit

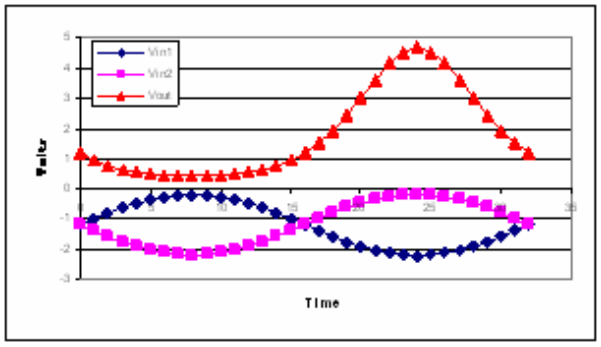

Figure 2: FeFET Diff. Amp.Voltage Transfer at -1.2V

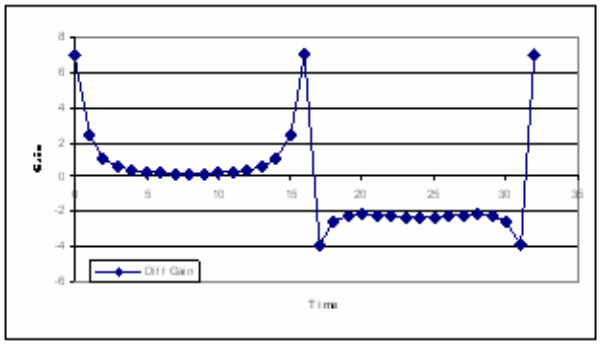

Figure 4: FeFET Differential Amplifier Gain vs. Time

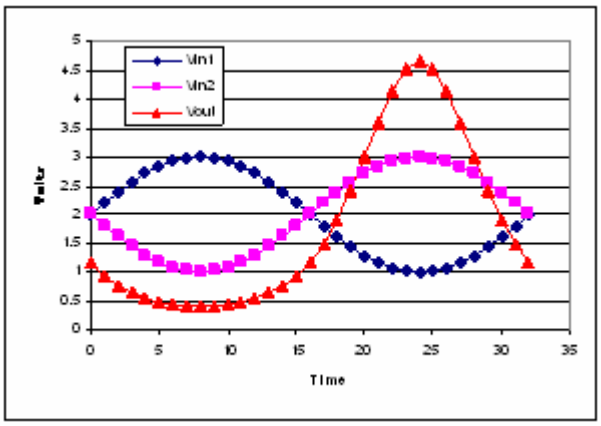

Figure 3: FeFET Diff. Amplifier Voltage Transfer at 2V

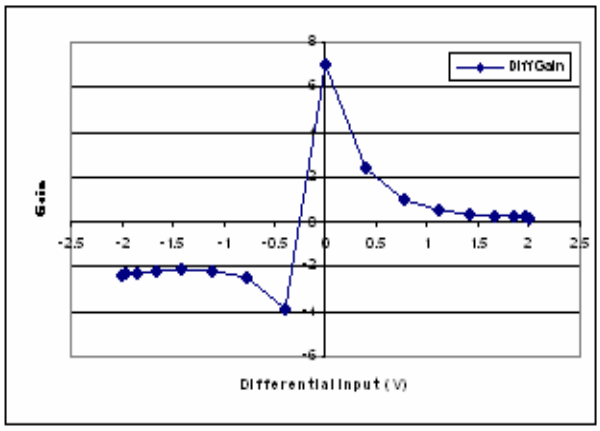

Figure 5: FeFET Differential Amplifier Gain vs. Input

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INTRODUCTION

- There has been considerable research investigating the Ferroelectric Field-Effect Transistor (FeFET) in memory circuits.
- However, very little research has been performed in applying FeFETs to analog circuits.
- This paper investigates the use of FeFETs in a common analog circuit, the differential amplifier.
- Goal to determine feasibility of using the FeFETs in the differential amplifier circuit.

FERROELECTRIC TRANSISTOR

- Initially the FeFET 4 x 400 transistors were characterized.
  - Channel length = 4 μm
  - Channel width = 400 μm
- FeFET active and remanent experimental data is shown in Figures 1 and 2, respectively. [1]

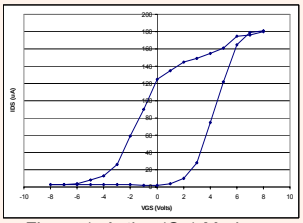

Figure 1: Active (On) Mode

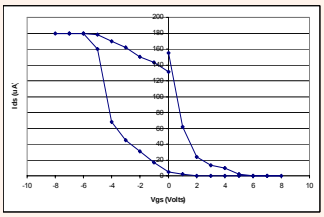

Figure 2: Remanent (Off) Mode

- Discontinuities in data are due to the experimental test setup data acquisition limitations. [2]

FERROELECTRIC DIFFERENTIAL AMPLIFIER

- The FeFET differential amplifier circuit is shown in Figure 3. [3]

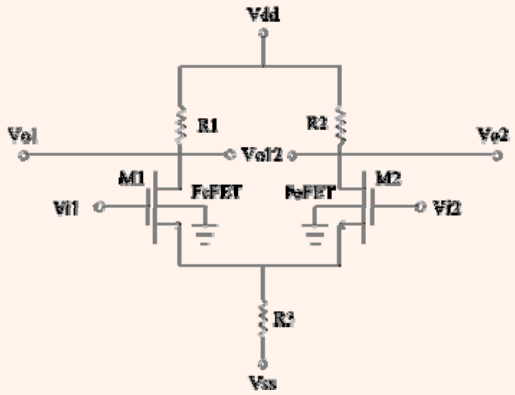

Figure 3: FeFET Differential Amplifier Circuit

- The two input Metal-Oxide-Semiconductor (MOS) transistors in a general MOS differential amplifier circuit are replace with 4 x 400 FeFETs M1 and M2.
- 400 KΩ resistors R1, R2, and R3 are used in place of the other three MOS transistors.
- Because of the FeFET hysteresis, the differential amplifier has four different operating modes depending on whether M1 and M2 are positively or negatively polarized.

EXPERIMENTAL RESULTS

- Oscilloscope plots for various amplifier inputs are shown in Figures 4 through 7. V_{i1} and V_{i2} are the blue and yellow traces and V_O is the red

Figure 4: V_{in} @ 100 Hz, 8 V_{p-p}, 0° phase difference. V_{O1} is shown.

Figure 5: V_{in} @ 100 Hz, 4 V_{p-p}, 180° phase diff., -1.0 Vdc offset. V_{O2} is shown.

Figure 6: V_{in} @ 1MHz, 4 V_{p-p}, 180° phase difference. V_{O2} is shown.

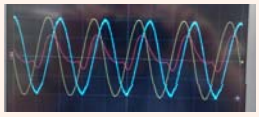

Figure 7: V_{in} @ 1MHz, 8 V_{p-p}, 90° phase difference. V_{O2} is shown.

- Comparison of FeFET diff. amp. to a standard MOSFET diff. amp. using MPF102 transistors is shown in Figures 8 through 11. V_{i1} and V_{i2} are the blue and yellow traces, V_{O1} is the green trace, V_{O2} is the pink trace, and

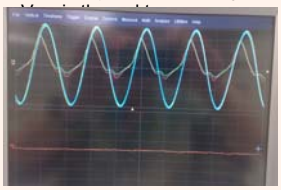

Figure 8: V_{in} @ 1KHz, 16 V_{p-p}, 0° phase difference

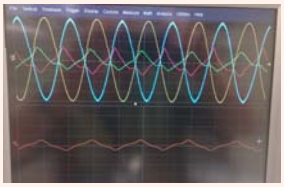

Figure 9: V_{in} @ 1KHz, 16 V_{p-p}, 180° phase difference

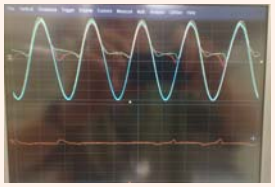

Figure 10: V_{in} @ 1KHz, 16 V_{p-p}, 0° phase difference

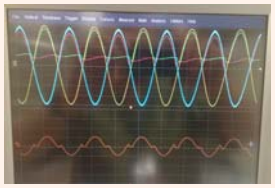

Figure 11: V_{in} @ 1KHz, 16 V_{p-p}, 180° phase difference

CONCLUSION

- The FeFET differential amplifier circuit produced some interesting results.
- Output signal characteristics changed with changes to input signal frequency and DC bias.
- The circuit operated over the tested frequency range of 100 Hz to 1MHz.
- From Figures 8 and 10, the common-mode gain of the FeFET diff. amp. and the MOSFET diff. amp. are both approximately zero, as desired.
- From Figures 9 and 11, the difference-mode gain of the FeFET differential amplifier is less than the MOSFET differential amplifer.

REFERENCES

[1] MacLeod, T. C. and Ho, F. D.: I-V Characteristics of a Ferroelectric Field Effect Transistor. Integrated Ferroelectrics. 2001; 34: 21-26.

[2] MacLeod, Todd, C., *A Study of the Characteristics of Ferroelectric Devices for use as Memory Circuits*, Master's Thesis, The University of Alabama in Huntsville, School of Graduate Studies, Huntsville, Alabama, 2007.

[3] Millman, Jacob, *Microelectronics: Digital and Analog Circuits and Systems*, New York: McGraw-Hill, 1979.