1.6V Analog Gaussian Mixture Model for Thyroid Disease Detection

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Outline

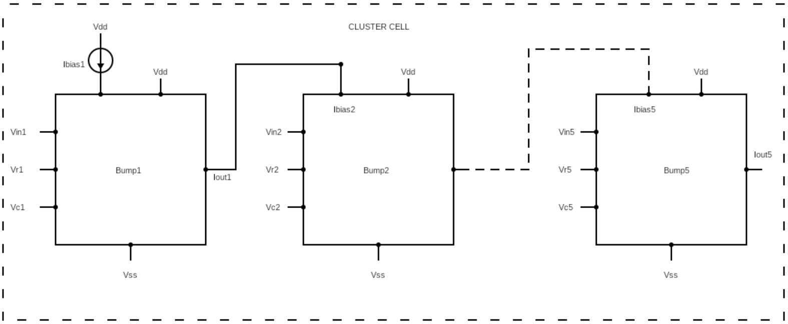
Introduction

Gaussian Mixture Model

- Mainly used for clustering problems
- It is based on the Gaussian function:
  $N(x_n \mid \mu_n, \sigma_n) = \frac{1}{\sqrt{(2*\pi*(\sigma_n)^2}} * e^{\frac{-(x_n-\mu_n)^2}{2*(\sigma_n)^2}}$ (1)
- Output distribution for class C and input vector X of size N: $N(X_i \mid M_i^c, \Sigma_i^c) = \Pi_{n=1}^{N} N(x_n | \mu_n^c, \sigma_n^c)$ (2)
- Could be used for classification problems via the Bayes theorem: $P(y_c \mid x) = \frac{P(x|y_c)P(y_c)}{P(x)}$ (3)
- Winning class is the one with the highest posterior probability: $y_{out} = argmax[P(y_c)P(x \mid y_c)]$ (4)

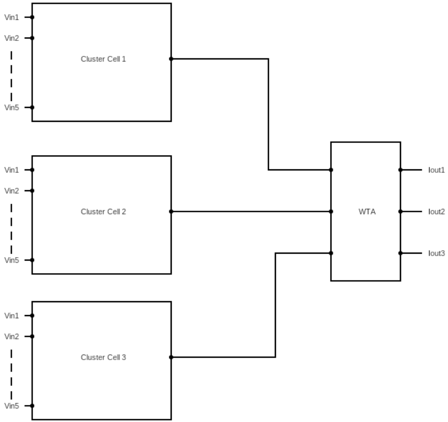
Analog Implementation of GMM

→ Analog computation of the 1-class output distribution of eq.(2) via a cluster cell:



Analog Implementation of GMM

→ Whole-system classifier, which includes 3 cluster cells and the argmax operator of eq.(4):



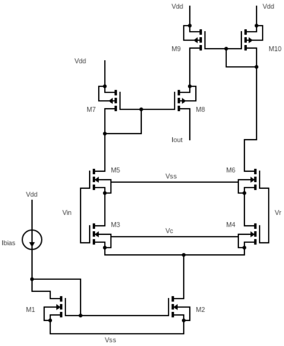
Circuits

Circuitry Workflow

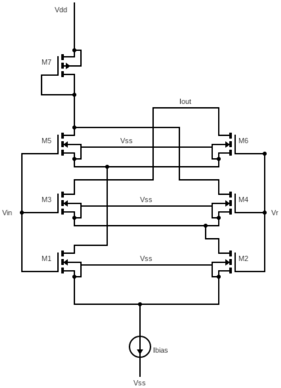
4 Different Circuits were tested and analyzed, 3 for the Gaussian Function and 1 for the argmax operator

- Bump Circuits
  1. Delbruck's Bump
  2. Gilbert's Bump
  3. Modified Bump
- Winner-Take-All Circuits:
  1. Lazarro NMOS WTA

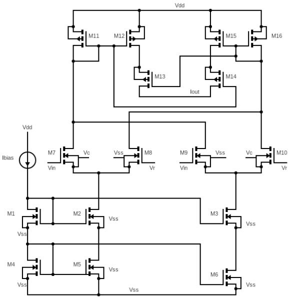
Gaussian Circuits



(a) Delbruck's Bump

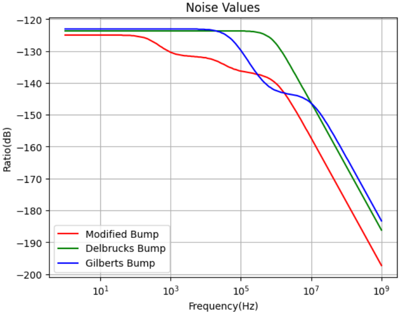


(b) Gilbert's Bump

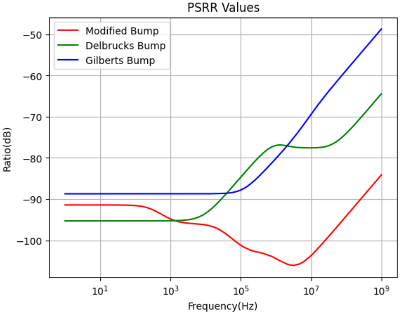


(c) Modified Bump

Noise and PSRR Comparison



(a) Noise Comparison between the 3 proposed bump circuits

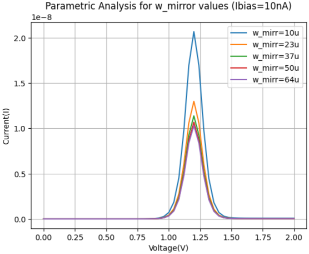


(b) PSRR Comparison between the 3 proposed bump circuits

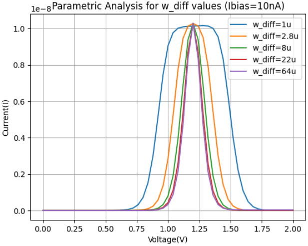
Specs Table for all 3 Bumps

Spec	Target	Delbruck's	Gilbert's	Modified
VDD	[1.6, 2.4]	1.6V	1.6V	1.6V
Ibias	<10uA	16nA	16nA	16nA
PSRR(1Hz)	>35dB	-95.2	-88.7	-91.4
PSRR(1kHz)	>12dB	-95.2	-88.7	-91.4
Noise(10Hz)	<-92dB	-123.6	-123.0	-124.9
Noise(100Hz)	<-100dB	-123.6	-123.0	-125.2
Noise(1kHz)	<-106dB	-123.6	-123.0	-130.3
Noise(10kHz)	<-110dB	-123.6	-123.2	-132
Noise(100kHz)	-	-123.7	-129.8	-136.3
Noise(1MHz)	<-140dB	-127	-142.4	-140.1

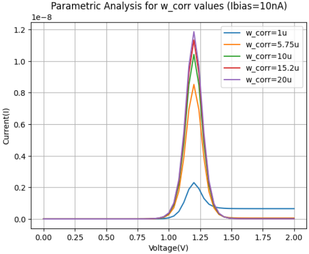
Parametric Analysis for transistor sizing



(a) Modified Bump results for different current mirror sizing

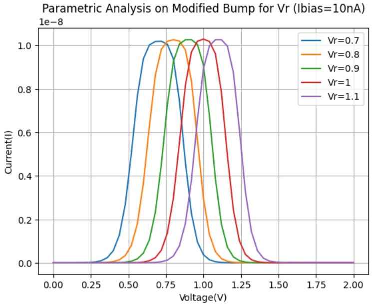


(b) Modified Bump results for different differential pair sizing

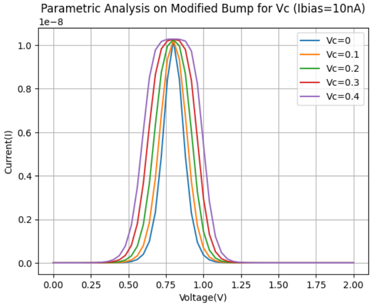


(c) Modified Bump results for different current correlator sizing

Parametric Analysis for gaussian mean and variance values



(a) Modified Bump results for different mean voltage values



(b) Modified Bump results for different variance voltage values

Final Parameters

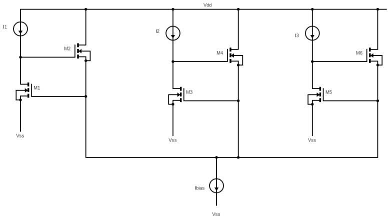
Parameter	Value
VDD	1.6V
Ibias	16nA
w_{mirr}	64u
w_{diff}	64u
w_{corr}	10u
M1-M4	$w_{mirr}/2$
M5-M6	$4^{*}w_{mirr}/2$
M7	$2^{*}w_{diff}/2$
M8-M9	$w_{diff}/2$
M10	$2^{*}w_{diff}/2$
M11	$4^{*}w_{corr}/2$
M12-M15	$w_{corr}/2$
M16	$4^{*}w_{corr}/2$

(a)Sizing and power parameters used for the modified bump

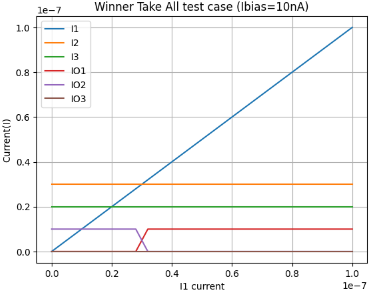
Parameter	Min Value	Max Value
V_r	0.8V	1.05V
V_c	0V	0.5V

(b)Mean and Variance parameters used for software training

WTA



(a) Curcuit Diagram of the Lazarro NMOS WTA



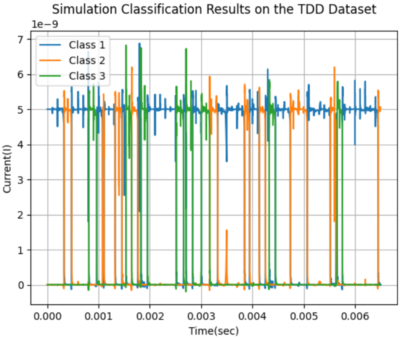
(b) Simulation Results for 3-class input currents

Results

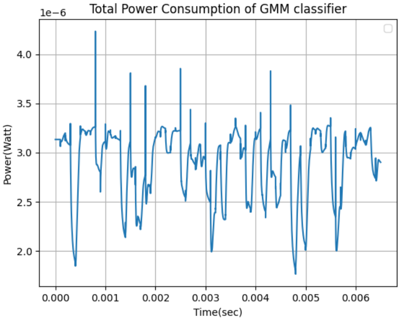
Thyroid Disease Data Set

- Use of Analog GMM to solve a real-world problem
- The dataset includes 5 blood test metrics
- 215 total instances for train and test
- 3 classes of patients:
  1. Normal Thyroid
  2. Hypothyroidism
  3. Hyperthyroidism

Simulation Results

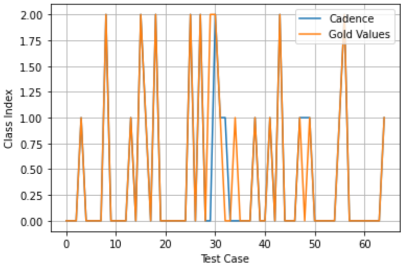


(a) Simulation current outputs for the Thyroid Dataset.



(b) Total Power Dissipation for classification on the Thyroid Dataset.

Software and Hardware Specs

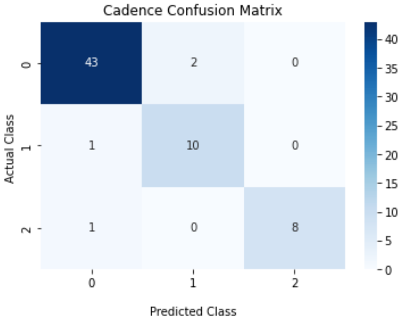


(a) Label comparison between software and hardware classification results

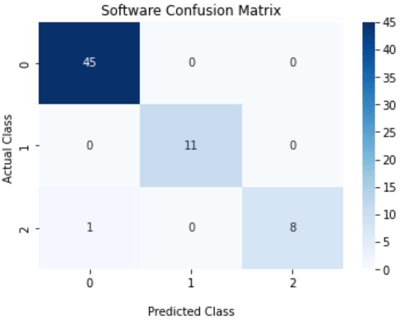
Spec	Target	Result
Software	>90%	98.4%
Hardware	>80%	93.8%
Power Consumption	<10uW	<4uW

(b)Accuracy and power specifications regarding the Thyroid Dataset

Confusion Matrices

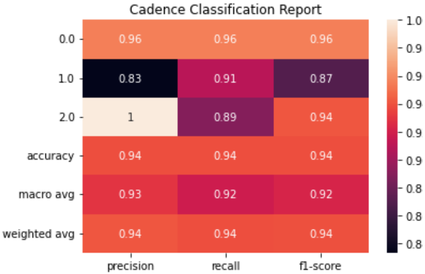


(a) Cadence Confusion Matrix

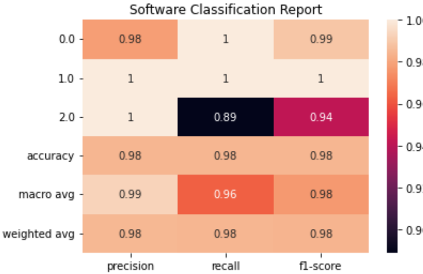


(b) Software Confusion Matrix

Classification Reports



(a) Cadence Classification Report



(b) Software Classification Report

Conclusions

Conclusions

- Implementation of GMM in analog circuits
- Low-power specifications (1.6V and 16nA)
- Adequate comparison of hardware implementation to its software counterpart
- Capability for real-time classification
- Use of the analog GMM for various other classification problems (skin detection, object recognition etc)

Thank you!