LECTURE 2 - HOW TO DESIGN TRIMMING CIRCUITS

Topics:

- Trimming circuit background
- Getting the information to design the trimming circuit
- Design procedures
- Examples

What will I learn?

- The principles of trimming circuits
- How to design a trimming circuit for a given application

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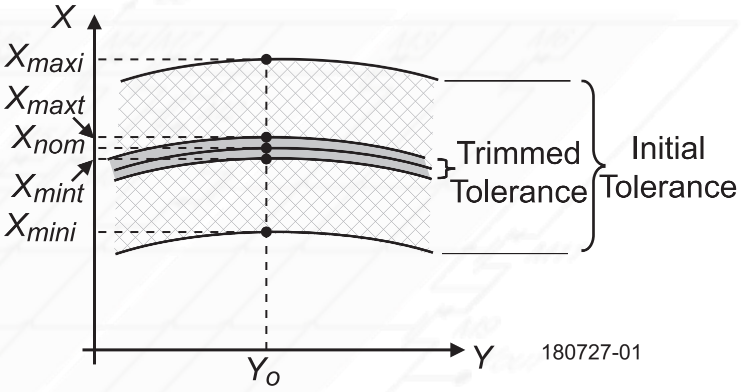
Trimming Design

Formulation

Assume X is some variable defined as:

X_{nom} = nominal value
X_{maxi} = initial max value
X_{mini} = initial min value
X_{maxt} = trimmed max value
X_{mint} = trimed min value



LSB and n are found as:

$$X_{LSB} = \frac{X_{maxt}-X_{mint}}{4} \quad \text{and} \quad n = \frac{ln\left(\frac{X_{maxi}-X_{mini}}{X_{LSB}}-1\right)}{\ln(2)}$$

Example:

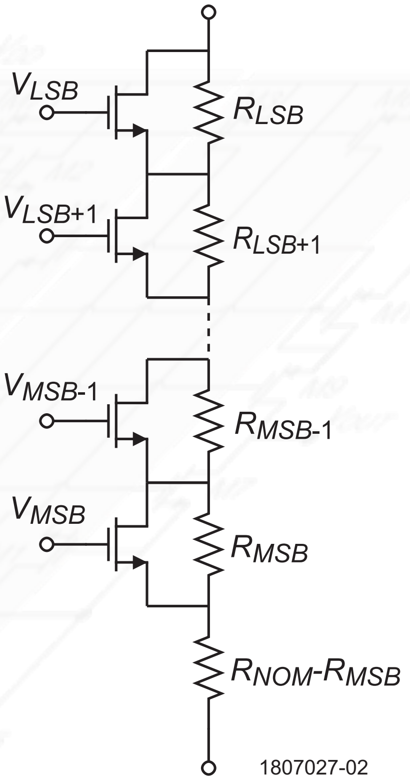
Let X_{nom}=20K, X_{maxi}=30K, X_{mini}=10K, X_{maxt}=21K, and X_{mint}=19K. X_{LSB} = 0.25(21K-19K) = 0.5K and n = 1.443ln[(30K-10K)/0.5K–1] = 5.29 → n = 6.

Trimming Implementation

Resistor

Switches:

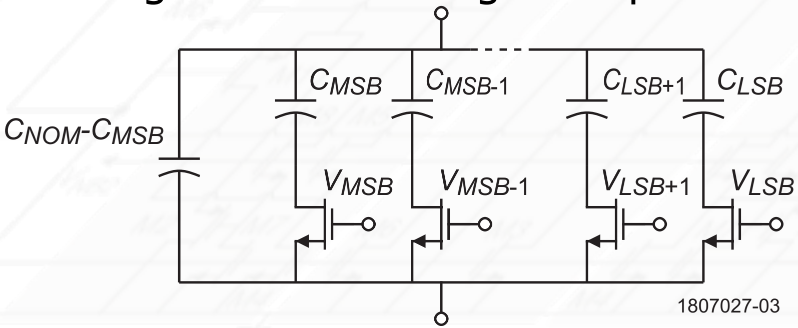
- $R_{ON} << R_{LSB}$
- Avoid leakage current at high temps



Capacitor

Switches:

- $R_{ON} << R_{ESR}$
- Avoid leakage current at high temps



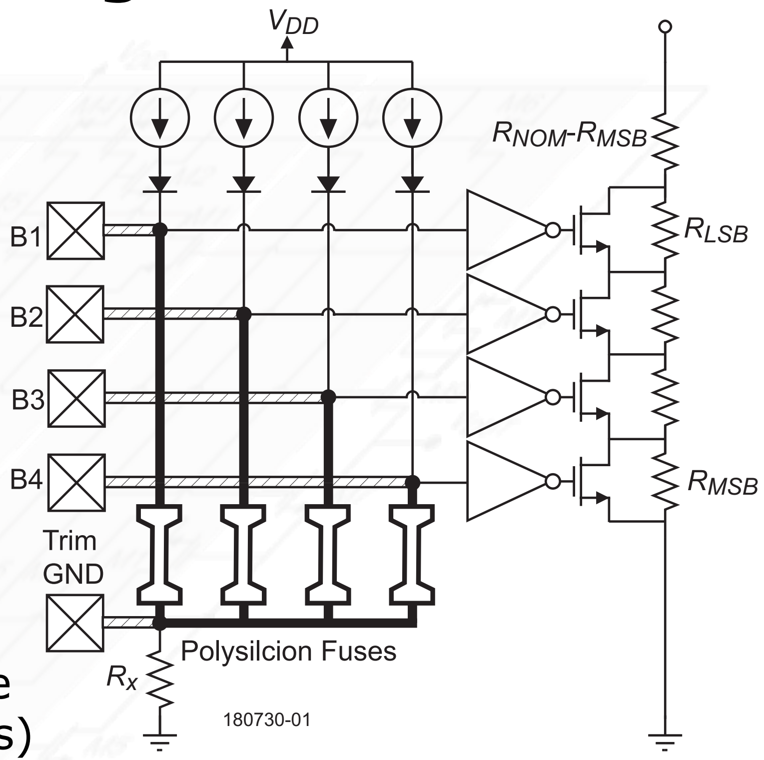
Programing Voltages

Memory Types

1. Fuses
2. Zener zap
3. Laser trimming
4. Nonvolatile memory

Fuse Example:

- Current sources provide a small current to pull the inverter high when fuse is open
- Diodes protect the current sources from the trimming current
- Pre-trim works by applying a voltage to B1 through B4 and successively determining which fuses should be blown (R_x reduces the current required from programming voltages)
- R_x is shorted out when trimming

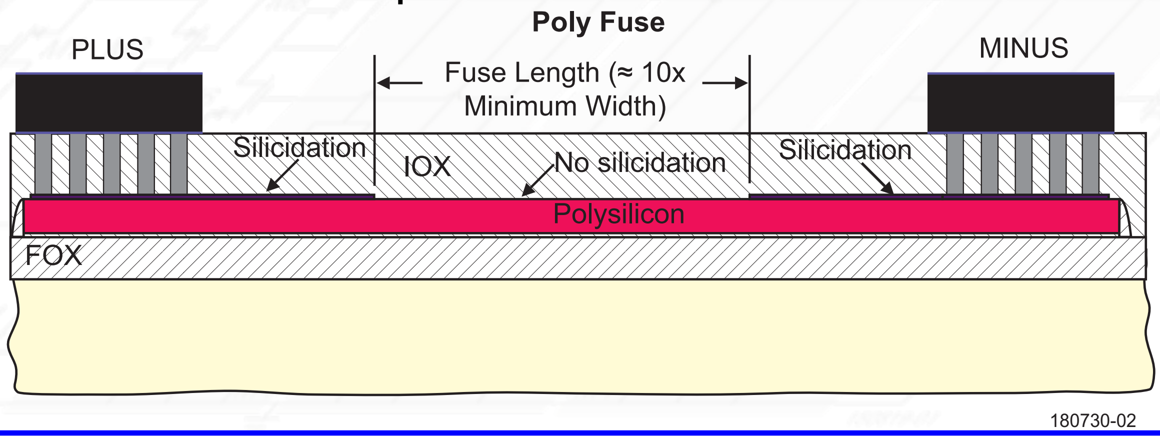


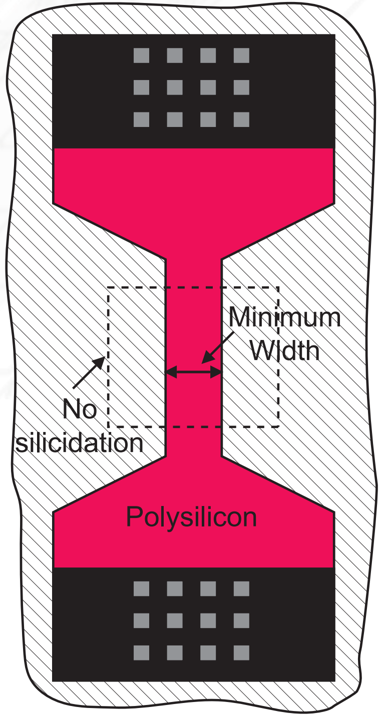
Polysilicon Fuses

Implementation

1. Short-narrow strip of unsilicided polysilicon
2. Initial fuse resistance ≈ 25Ω blown fuse resistance ≈ 100MΩ
3. Fuse current ≈ 30mA and fuse voltage ≈ 6V
4. Programming time ≈ 10ms with Rise/fall time ≈ 100V/μs

Polysilicon Fuse Example:





Trimming Design

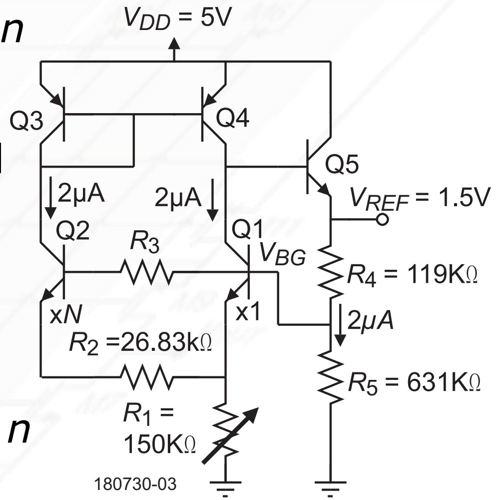
Trimming Design Procedure DT1

Step	Design	Comments
1	Find X_{nom}, X_{maxi}, X_{mini}, X_{maxt}, and X_{mint}	Use worst case corners or Monte Carlo simulation
2	Let	
3	Let	
4	Untrimmed $X = X_{nom} - X_{msb}$	It may be necessary to re-center the untrimmed X
5	Trimmed X's = X_{LSB}, $2X_{LSB}$, …, $0.5X_{MSB}$, X_{MSB}	
6	Select memory type and implement accordingly	

Brokaw BG Trimming Design

Example 1

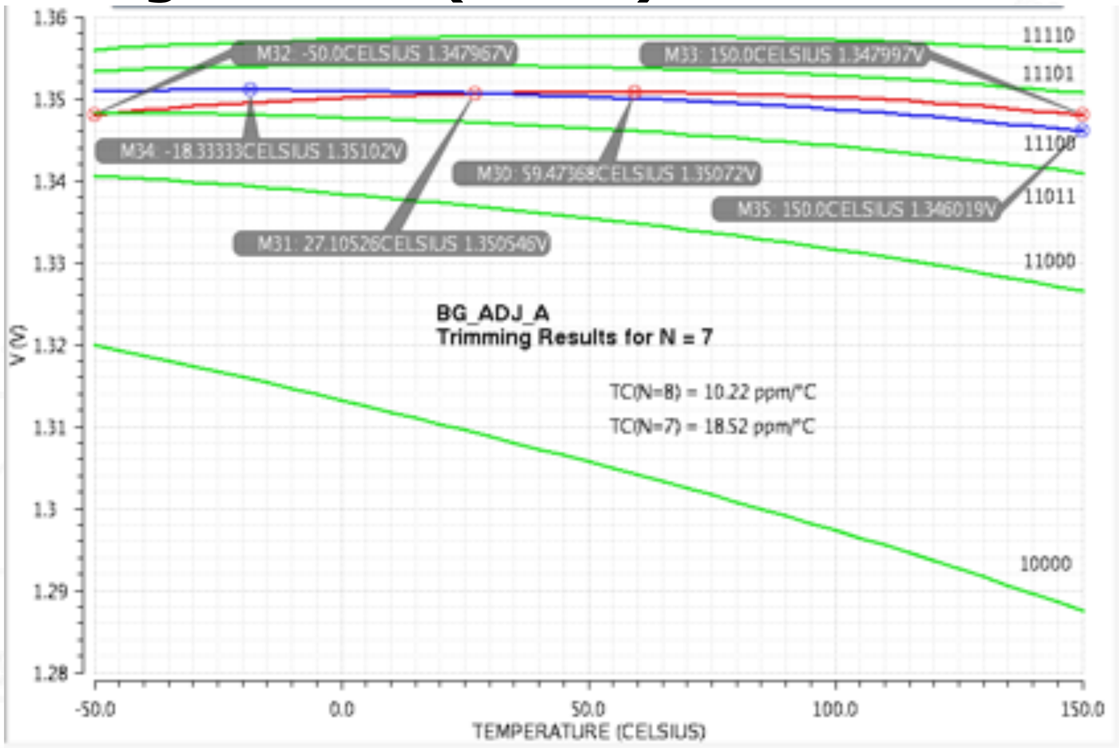
The Brokaw BG of Example 2 of Lecture 2 of the *How to Design Bias Circuit* series experienced a V_{REF} change of ±3% when N was changed from 8 to 7 and 8 to 9 (to estimate process influenced). Design a trimming circuit for R_1 (150kΩ) that will bring the final tolerance of V_{REF} to within ±0.5%.



1. $V_{LSB} = \frac{V_{REF(maxt)} - V_{REF(mint)}}{4} = 0.25(1.5x1.005 - 1.5x0.995) =$ 3.75mV
2. $n = \frac{ln\left(\frac{V_{REF(maxi)} - V_{REF(mini)}}{V_{LSB}} - 1\right)}{\ln(2)} = \frac{ln\left(\frac{1.545 - 1.455}{0.00375} - 1\right)}{\ln(2)} = \frac{3.1355}{.6931} = 4.52 \rightarrow n = 5$
3. $R_{LSB} = V_{LSB}/2I_{PTAT}$ = 3.75mV/4μA = 937.5Ω
4. R_{LSB+1} = 1.875kΩ, R_{LSB+2} = 3.75kΩ, R_{LSB+3} = 7.5kΩ, and R_{MSB} = 15kΩ
5. R_{NOM}-R_{MSB} = 150KΩ – 15KΩ = 135KΩ

Brokaw BG Trimming Design

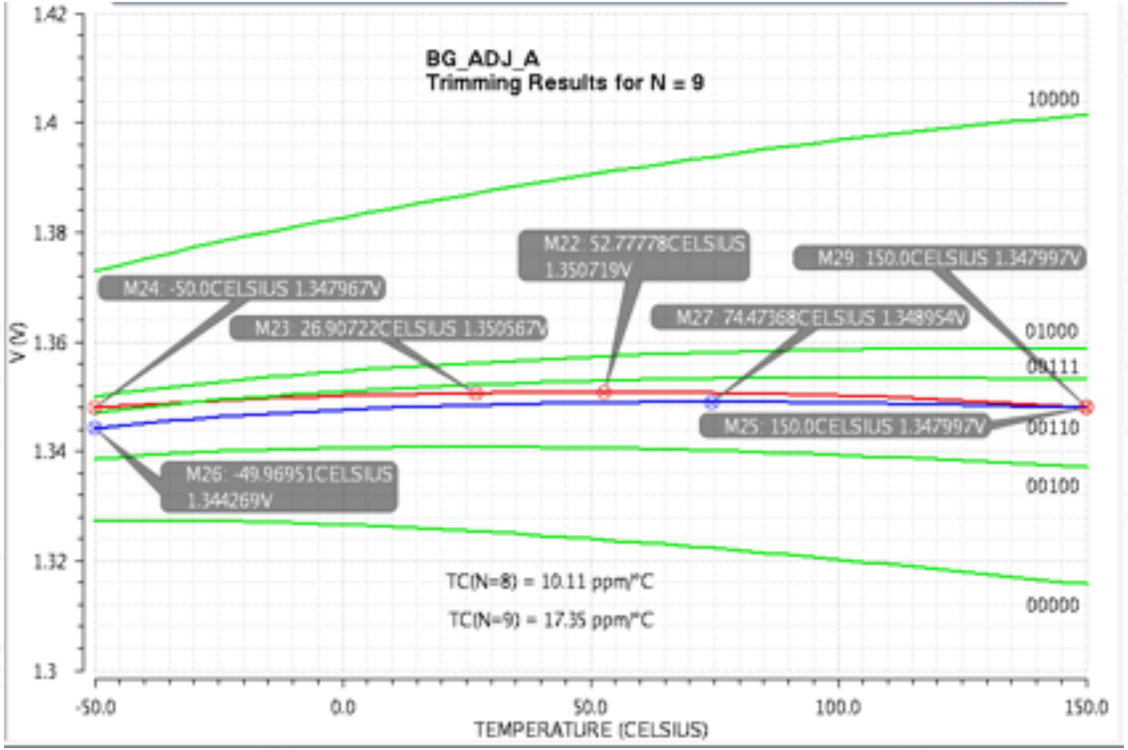
Trimming Results (N = 7)



Red is for *N* = 8
Blue is the best trimmed for *N* = 7 (11100)

Brokaw BG Trimming Design

Trimming Results (N = 9)



Red is for N = 8
Blue is the best trimmed for N = 9 (00110)

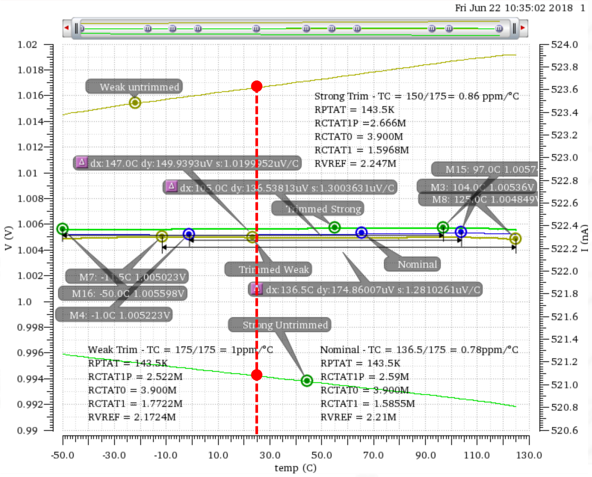
R_4 could have been trimmed to help adjust the value of V_{REF}

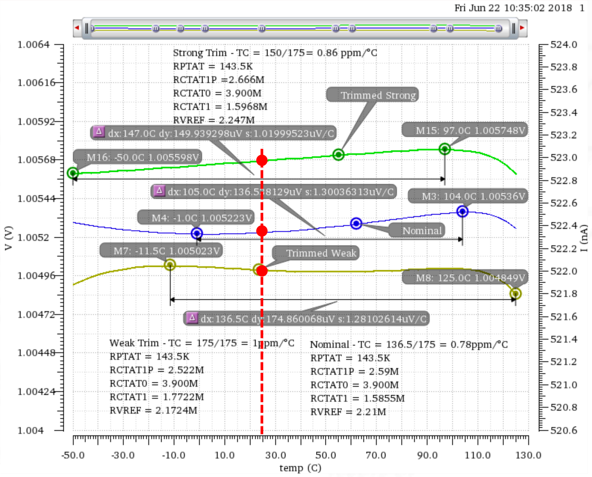
Ultra-Stable BG Trimming Design

Example 2

The resistors R_{CTAT1P}, R_{CTAT1}, and R_{VREF} were adjusted in the figure shown to bring the TC back to within 1ppm/°C for strong and weak corners of the ultra-stable BG of Example 1 of Lecture 4 of the *How to Design Bias Circuit.* Design a trimming circuit for these resistors to implement the strong and weak case simulation results.

First find the BG voltages from the plots below at 25°C for V_{nom}, V_{maxt}, V_{mint}, V_{maxi}, and V_{mini} which are summarized below.





V_{nom}	1.005225V
V_{maxt}	1.005689V
V_{mint}	1.004962V
V_{maxi}	1.0163V
V_{mini}	0.9942V

Ultra-Stable BG Trimming Design

Example 2 - Continued

Using the DT1 design procedure, we get

V_{LSB} = 179.5µV, n = 6.93 → 7, and R_{LSB} = 179.5µV/0.25µA = 718Ω

The values for the trimming R_{CTAT1P}, R_{CTAT1}, and R_{VREF}, are shown below.

Bit #	RCTAT1P(Ω)	RCTAT1(Ω)	RVREF(Ω)
1	718	718	718
2	1436	1436	1436
3	2872	2872	2872
4	5744	5744	5744
5	11488	11488	11488
6	22976	22976	22976
7	45952	45952	45952
Nom-MSB	2.5040E+06	1.5940E+06	2.1640E+06
Max	2.5952E+06	1.6852E+06	2.2552E+06
Min	2.5040E+06	1.5940E+06	2.1640E+06

If we compare the values in the table with those on the figures of the previous side, we see that the trim range is not sufficient for RCTAT1P and RCTAT1. For RCTAT1P increase the number of bits to 8 and let R_{NOM}-R_{MSB} be 2.55MΩ. For RCTAT1 increase the number of bits to 8 and let R_{NOM}-R_{MSB} be 1.64MΩ.

Summary

Design of Trimming Circuits

- Trimming design formulation
- Implementation
- Programming methods
- Design Procedure DT1
- Examples
- It is necessary to check the results to make sure the number of bits and the value of the untrimmed contribution is centered correctly