ECE-1777: Computer Methods for Circuit Simulation

Instructor: Farid N. Najm, (416) 946-5175, f.najm@utoronto.ca, office in SF1024.
Web Site: www.eecg.utoronto.ca/∼najm

Prerequisites:
ECE-212 and Math-298, or equivalent (circuit theory linear algebra), as well as programming in C or C++.

General Description: Circuit simulation is a very commonly used technique for analysis and verification of electronic and electric circuits, ranging from integrated circuits and microelectronics to power distribution networks and power electronics. It is both an established art and an important area of further research. This course covers the theoretical background for modern circuit simulation, as well as the numerical techniques that are at the core of typical circuit simulators.

Topical Overview

Topic	Reading
I. Introduction	**Chapter 1**
01. Circuit Simulation	
II. Network Equations	**Chapter 2**
02. Elements and Networks	
03. Topological Constraints	
04. Cycle Space and Bond Space	
05. Formulation of Linear Algebraic Equations	
06. Formulation of Linear Dynamic Equations	
III. Solution of Linear Algebraic Circuit Equations	**Chapter 3**
07. Direct Methods	
08. Indirect/Iterative Methods	
09. Partitioning Techniques	
10. Sparse Matrix Techniques	
IV. Solution of Nonlinear Algebraic Circuit Equations	**Chapter 4**
11. Formulation of Nonlinear Network Equations	
12. Solution Techniques	
13. Application to Circuit Simulation	
V. Solution of Differential Circuit Equations	**Chapter 5**
14. Formulation of Differential Network Equations	
15. Solution Techniques	
16. Application to Circuit Simulation	
VI. Conclusion	
17. Circuit Simulation	

Grading: The course mark will be based on 8 homework assignments and 3 computer projects: Homework 1 (20 points), 2 (50), 3 (20), 4 (30), 5 (25), 6 (50), 7 (60), and 8 (70); Project 1 (50), 2 (50), and 3 (50), for a total of 475 points that constitute the full course mark.

Disclaimer: Less than 5% of the evaluation for this course will be returned to you before the last date to drop courses. Students should be aware of this in making any decision whether or not to remain in the course past the drop date. No requests for late withdrawal will be supported on the grounds that insufficient feedback was available before the drop date.

Textbook: F. N. Najm, *Circuit Simulation*, Wiley-IEEE Press, 2010 [ISBN: 978-0-470-53871-5]. **(consult the list of known errors, below and online at eecg.utoronto.ca/∼najm/simbook)**

Detailed Course Outline

Lecture	Reading	Assignments
Part I. Introduction		
01. Introduction	1.1–1.4	
Part II. Network Equations		
02. Elements and Networks	2.1–2.2	
03. Cycle and Bond Spaces	2.2–2.3	Homework 1 out (1wk)
04. Linear Algebraic Equations	2.4.1–2.4.3	
05. Modified Nodal Analysis	2.4.4–2.5.2	
Part III. Solution of Linear Algebraic Circuit Equations		
06. Solving Linear Algebraic Equations	3.1.1	Homework 2 out (1wk)
07. Gaussian Elimination	3.1.2–3.1.3	
08. LU Factorization	3.1.3	
09. LU Factorization	3.1.3–3.1.5	Homework 3 out (1wk)
10. Accuracy and Stability	3.2.1	Project 1 out (3wks)
11. Stability of GE	3.2.2–3.2.5	
12. Pivoting for Accuracy	3.2.5–3.2.6	Homework 4 out (1wk)
13. Conditioning	3.2.6–3.2.7	
14. Iterative Methods	3.3	
15. Partitioning	3.4	
16. Sparse Matrix Methods	3.5.1–3.5.4	
17. Markowitz Pivoting	3.5.5–3.5.7	
18. Pivoting for Sparsity	3.5.8–4.1	Homework 5 out (1wk)
Part IV. Solution of Nonlinear Algebraic Circuit Equations		
19. Nonlinear Algebraic Circuit Equations	4.1–4.2.1	
20. Introduction to Newton's Method	4.2.2–4.2.3	
21. Newton's Method	4.2.3–4.2.4	Homework 6 out (2wks)
22. Quasi-Newton Methods	4.2.5–4.3.2	
23. Application to Simulation	4.3.3–4.3.6	
24. Companion Models	4.3.6–4.3.7	Project 2 out (4wks)
25. Quasi-Newton Methods in Simulation	4.4.1	
26. Continuation and Homotopy Methods	4.4.2–4.4.5	
Part V. Solution of Differential Circuit Equations		
27. Differential Circuit Equations	5.1.1–5.2.1	Homework 7 out (2 wks)
28. Overview of Solution Methods	5.2.1–5.2.3	
29. Quality Metrics	5.2.4	
30. Linear Multistep Methods	5.2.5–5.3.4	
31. Deriving the LMS Methods	5.3.5–5.3.7	
32. Local Truncation Error	5.3.7–5.3.8	
33. Stability of LMS Methods	5.4.1–5.4.3	Homework 8 out (2 wks)
34. Regions of Absolute Stability	5.4.3–5.4.6	
35. Trapezoidal Ringing	5.5–5.6	
36. Application to Simulation	5.7.1–5.7.3	Project 3 out (3wks)
37. Discretization	5.7.3–5.7.4	
38. Charge/Flux-Based Models	5.7.5	
39. MTEs and Time-Step Control	5.7.6–5.7.9	

Errata

1. On page 31, in equation (2.42), the g_{ii} on the left-hand-side should be the absolute value $|g_{ii}|$. Once corrected, the equation should be as follows:

$$|g_{ii}| > \sum_{\forall j \neq i} |g_{ij}|$$

2. On page 32, in the 2nd line from the bottom, that sentence should start with "For each of" instead of "For of".
3. On page 112, in the 2nd line below equation (3.229), the word "unsable" should be "unusable".
4. On page 132, in the equation right after equation (4.13), and in the one right after equation (4.14), the top-right entry of the G matrix (the large matrix on the left-hand side) should be 1 instead of 0.
5. On page 175, in equation (4.172), in the middle case (linear), the expression for the current should be further multiplied by $(1 + \lambda v_{ds})$. Once corrected, the equation should be as follows:

$$i_d = \begin{cases} 0, & \text{if } v_{gs} \leq V_t \text{ (cut-off);} \\ \beta \left[(v_{gs} - V_t) v_{ds} - \frac{1}{2} v_{ds}^2 \right] (1 + \lambda v_{ds}), & \text{if } 0 \leq v_{ds} \leq v_{gs} - V_t \text{ (linear);} \\ \frac{\beta}{2} (v_{gs} - V_t)^2 (1 + \lambda v_{ds}), & \text{if } 0 \leq v_{gs} - V_t \leq v_{ds} \text{ (saturation).} \end{cases}$$

6. On page 175, in the displayed equation that gives the value of G_{ds}, in the middle case (linear), the expression for G_{ds} should be changed to: $(\beta/2)\lambda v_{ds}^2 + \beta(v_{gs} - V_t - v_{ds})(1 + 2\lambda v_{ds})$. Once corrected, the equation should be as follows:

$$G_{ds} \triangleq \frac{\partial i_d}{\partial v_{ds}} = \begin{cases} 0, & \text{if } v_{gs} \leq V_t; \\ \frac{\beta}{2} \lambda v_{ds}^2 + \beta (v_{gs} - V_t - v_{ds})(1 + 2\lambda v_{ds}), & \text{if } 0 \leq v_{ds} \leq v_{gs} - V_t; \\ \frac{\beta}{2} \lambda (v_{gs} - V_t)^2, & \text{if } 0 \leq v_{gs} - V_t \leq v_{ds}. \end{cases}$$

7. On page 175, in the displayed equation that gives the value of g_m, in the middle case (linear), the expression for g_m should be changed to: $\beta v_{ds}(1 + \lambda v_{ds})$. Once corrected, the equation should be as follows:

$$g_m \triangleq \frac{\partial i_d}{\partial v_{gs}} = \begin{cases} 0, & \text{if } v_{gs} \leq V_t; \\ \beta v_{ds} (1 + \lambda v_{ds}), & \text{if } 0 \leq v_{ds} \leq v_{gs} - V_t; \\ \beta (v_{gs} - V_t)(1 + \lambda v_{ds}), & \text{if } 0 \leq v_{gs} - V_t \leq v_{ds}. \end{cases}$$

8. On page 176, in equation (4.179), the expression for the current in the middle case should be further multiplied by $(1 + \lambda v_{ds}^{(k)})$. Once corrected, the equation should be as follows:

$$i_d^{(k)} = \begin{cases} 0, & \text{if } v_{gs}^{(k)} \leq V_t; \\ \beta \left[(v_{gs}^{(k)} - V_t) v_{ds}^{(k)} - \frac{1}{2} {v_{ds}^{(k)}}^2 \right] \left(1 + \lambda v_{ds}^{(k)} \right), & \text{if } 0 \leq v_{ds}^{(k)} \leq v_{gs}^{(k)} - V_t; \\ \frac{\beta}{2} (v_{gs}^{(k)} - V_t)^2 \left(1 + \lambda v_{ds}^{(k)} \right), & \text{if } 0 \leq v_{gs}^{(k)} - V_t \leq v_{ds}^{(k)}. \end{cases}$$

9. On page 233, in the line right before equation (5.148) β_{n-j} should be changed to β_j.
10. On page 234, equation (5.149) should say $= 0$ at the right end, as follows:

$$C_0 = C_1 = \cdots = C_p = 0$$

11. On page 249, the paragraph around the middle of the page starts out with "What do we learn from the region of absolute stability FE?". This should have the word "of" inserted before FE.
12. On page 250, the paragraph around the middle of the page starts out with "What do we learn from the region of absolute stability BE?". This should have the word "of" inserted before BE.
13. On page 251, the paragraph near the bottom of the page starts out with "What do we learn from the region of absolute stability TR?". This should have the word "of" inserted before TR.
14. On page 261, in the 2nd line of text after equation (5.262), it says " ... in the sense that is only accurate ...". The word " it" should be inserted between "that" and "is".

Additional References

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