## Contents

### ANALOG

**Chapter 1: Foundations**  
*Overview: Chapter 1* ............................................ 1  
Class 1: DC Circuits ............................................. 3  
  Worked example: Resistors & instruments .................. 15  
Lab 1: DC circuits ............................................. 24  

Class 2: Capacitors & RC Circuits ............................ 32  
  Worked example: RC circuits .................................. 46  
  A Note on reading capacitor values ......................... 51  
Lab 2: Capacitors ............................................. 54  

Class 3: Diode Circuits ........................................ 61  
  Worked example: Power supply .............................. 71  
Lab 3: Diode circuits ......................................... 75  
  *Wrap-up: Ch. 1: Review* ................................... 80  
  Jargon and terms ........................................... 81  

**Chapter 2: Transistors (bipolar)**  
*Overview: Chapters 2 & 3* .................................. 82  
Class 4: Transistors I: First Model ......................... 84  
  Worked example: Emitter follower .......................... 90  
Lab 4: Transistors I ........................................... 94  

Class 5: Transistors II: Corrections to the first model: Ebers-Moll; $r_e$; applying this new view ............................................. 100  
  Worked example: Common-emitter amplifier (bypassed emitter) .................................................. 115  
Lab 5: Transistors II ........................................... 118  

Class 6: Transistors III: Differential amplifier; Miller effect .................................................. 124  
  Worked example: Differential amplifier ..................... 131  
Lab 6: Transistors III ........................................... 134  
  *Wrap-up Ch. 2: Review* ................................... 139  
  Jargon and terms ........................................... 140  

**Chapter 3: Field Effect Transistors**  
Class 7: FETs I (linear applications) ........................ 142  
  Worked example: Current source, source follower ........ 153  
Lab 7: FETs I (linear) ......................................... 156  
  *(We return to FETs in Lab 11)*  

**Chapter 4: Feedback and Operational Amplifiers**  
*Overview: Feedback: Chapters 4, 5 & 6* ................. 163  
Class 8: Op Amps I: Idealized view ......................... 166  
  Worked Example: Inverting amplifier; summing circuit .................................................. 175  
Lab 8: Op amps I .............................................. 175  

Class 9: Op Amps II: Departures from ideal ................ 184  
  Worked example: Integrators; effects of op amp errors ................................................. 196  
Lab 9: Op amps II .............................................. 200  

**Chapter 4 (continued); Chapter 5 Active Filters & Oscillators**  
Class 10: Op Amps III: Positive Feedback, Good and Bad: comparators, oscillators, and unstable circuits; a quantitative view of the effects of negative feedback ............................................. 207  
  Appendix: Notes on op amp frequency compensation .................................................. 222  
  Worked example: Effects of feedback (quantitative) .................................................. 224  
    Schmitt trigger ............................................ 227  
    Op Amp Innards: Annotated schematic of the LF411 ............................................. 232  
Lab 10: Positive feedback, good and bad .................... 233  
  *Wrap-up Chs. 4 & 5: Review* .............................. 242  
  Jargon and terms ........................................... 243  

**Chapter 3: Field Effect Transistors (revisited)**  
Class 11: FETs II: Switches (power switching and analog switch applications) ......................... 244  
  Worked example: Sample and hold ......................... 250  
Lab 11: FET switches ........................................... 255  
  *Wrap-up Ch. 3: Review* ................................... 264  
  Jargon and terms ........................................... 265  

**Chapter 6: Voltage Regulators and Power Circuits**  
Class 12: Voltage Regulators ................................ 267  
Lab 12: Voltage regulators ................................... 274  
  *Wrap-up Ch. 6: Jargon and terms* ........................ 280
<table>
<thead>
<tr>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 19: Assembly Language; Inside the CPU; I/O Decoding ........................................ 455</td>
</tr>
<tr>
<td>Supplementary notes: introduction to assembly language ........................................ 467</td>
</tr>
<tr>
<td>Lab 19: µ2: I/O .................................................. 471</td>
</tr>
<tr>
<td>Class 20: µ3: A/D ↔ D/A Interfacing; Masks; Data tables ........................................ 479</td>
</tr>
<tr>
<td>Lab 20: Subroutines; More I/O Programming .................................................. 489</td>
</tr>
<tr>
<td>Class 21: µ4: More Assembly-Language Programming; 12-bit port ..................................... 498</td>
</tr>
<tr>
<td>Worked example: 10 tiny programs .................................................. 503</td>
</tr>
<tr>
<td>Worked Example: 12-bit frequency counter .................................................. 518</td>
</tr>
<tr>
<td>Hand assembly: table of codes .................................................. 521</td>
</tr>
<tr>
<td>Lab 21: A/D, D/A, Data Handling .................................................. 525</td>
</tr>
<tr>
<td>Class 22: µ5: Interrupts &amp; Other 'Exceptions' .................................................. 535</td>
</tr>
<tr>
<td>Debugging aid: Register Check in two forms .................................................. 541</td>
</tr>
<tr>
<td>Lab 22: 'Storage scope'; Interrupts &amp; other 'exceptions' .................................................. 548</td>
</tr>
<tr>
<td>Class 23: µ6: Wrap-up: Buying and Building .................................................. 562</td>
</tr>
<tr>
<td>Lab 23: Applying your microcomputer ('Toy Catalog') .................................................. 567</td>
</tr>
<tr>
<td>Wrap-up Chapters 10, 11: Review .................................................. 586</td>
</tr>
<tr>
<td>Jargon and terms .................................................. 587</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appendix:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Equipment and Parts List .................................................. 588</td>
</tr>
<tr>
<td>B Selected data sheets</td>
</tr>
<tr>
<td>2N5485 JFET .................................................. 592</td>
</tr>
<tr>
<td>DG403 analog switch .................. 593</td>
</tr>
<tr>
<td>74HC74 dual D FLIP-FLOP ............... 595</td>
</tr>
<tr>
<td>AD7569 8-bit A/D, D/A .................. 597</td>
</tr>
<tr>
<td>68008 execution times and timing diagram .................................................. 600</td>
</tr>
<tr>
<td>25120 write-only memory ............... 605</td>
</tr>
<tr>
<td>C Big Picture: Schematic of lab microcomputer .................................................. 606</td>
</tr>
<tr>
<td>D Pinouts .................................................. 608</td>
</tr>
</tbody>
</table>

| Index .................................................. 612 |
Contents

Laboratory Exercises *(a more detailed listing)*

**PART I: ANALOG LABS**

**Lab 1. DC Circuits**
- Ohm’s law; A Nonlinear device; The diode; Voltage divider; Thevenin model;
  Oscilloscope; AC voltage divider

**Lab 2. Capacitors**
- RC circuit; Differentiator; Integrator; Low-pass filter; High-pass filter; Filter example
  I; Filter example II; Blocking capacitor; LC filter

**Lab 3. Diodes**
- LC resonant circuit; Confirming Fourier series; Half-wave rectifier; Full-wave bridge
  rectifier; Ripple; Signal diodes; Diode clamp; Diode limiter; Impedances of test
  instruments

**Lab 4. Transistors I**
- Transistor junctions are diodes; Emitter follower; Transistor current gain; Current
  source; Common emitter amplifier; Transistor switch

**Lab 5. Transistors II**
- Dynamic diode curve tracer; Grounded emitter amplifier; Current mirror; Ebers-Moll
  equation; Biasing: good & bad; Push-Pull

**Lab 6. Transistors III**
- Differential amplifier; Bootstrap; Miller effect; Darlington; Superbeta

**Lab 7. Field Effect Transistors I**
- FET characteristics; FET current sources; Source follower; FET as Voltage-
  controlled resistance; Amplitude modulation; ‘Radio broadcast’

**Lab 8. Op Amps I**
- Op-amp open-loop gain; Inverting amplifier; Non-inverting amplifier; Follower;
  Current source; Current-to-voltage converter; Summing amplifier; Push-pull
  buffer

**Lab 9. Op Amps II**
- Op-amp limitations; AC amplifier; Integrator; Differentiator; Active rectifier; Active
  clamp

**Lab 10. Oscillators**
- Comparator; Schmitt trigger; IC relaxation oscillator; Sawtooth wave oscillator;
  Voltage-controlled oscillator; Wien bridge sine oscillator; Unwanted oscillations:
  discrete follower & op amp stability problems

**Lab 11. Field Effect Transistors II**
- Analog switch characteristics; Applications: chopper circuit; sample-&-hold;
  switched-capacitor filters; negative voltage from positive

**Lab 12. Power Supplies**
- The 723 regulator; Three-terminal fixed regulator; Three-terminal adjustable
  regulator;
- Three-terminal regulator as current source; Voltage reference; ‘Crowbar’ clamp
Contents

PART II: DIGITAL LABS

Lab 13. Gates
- Logic probe; IC gates: TTL & CMOS; Logic functions with NANDs; Gate innards: TTL; CMOS: CMOS NOT, NAND, 3-state

Lab 14. Flip-Flops
- Latch; D flop; J-K flop; Ripple counter; Synchronous counter; Shift-register; Digitally-timed one-shot

Lab 15. Counters
- 8-bit counter; Cascading; Load from keypad; Programmable divide-by-n counter; Period meter; Capacitance meter

Lab 16. Memory; State Machines
- RAM; Divide-by-3 (your design); Memory-based state machines: Single-loop; External control added

Lab 17. A/D; Phase-Locked Loop: Two Digital Feedback Machines:
- D/A; A/D: Slow motion; Full speed; Displaying search tree; Speed limit; Latching output; Phase-Locked Loop: frequency multiplier.

Lab 18. µ1: Adding CPU
- Clock; CPU preliminary test; Fixing busgrant*; Memory enable logic; Memory write logic; Single-step; Test program; Full-speed: timing diagram

Lab 19. µ2: I/O: Output: First small programs
- Battery backup; Power-fail detector; I/O decoder; Data displays; Timing program

Lab 20. µ3: Input; More small programs
- Delay as subroutine; Improved delay routines; Input hardware: Data input hardware; Input/output program; Ready signal; I/O program with enter/ready function; Decimal arithmetic

Lab 21. µ4: A/D ↔ D/A
- A/D-D/A wiring details; Programs: confirming that D/A, A/D work; In & Out; Invert, rectify, low-pass;

Lab 22. µ5: ‘Storage scope;’ Interrupts & other ‘Exceptions’
- ‘Storage scope;’ keyboard control;
  Exceptions: A software exception: illegal; Interrupt: hardware to request interrupt;
  Program: main & service routine; NMI; Applying interrupts

Register-Check: a debugging aid (optional program; install if you choose to)

Lab 23. Applying Your Microcomputer (‘Toy Catalog’)
- X-Y scope displays; Light-pen; Voice output; Driving a stepper motor; Games;
  Sound sampling/generation