

CONTENTS

<i>Preface to the third edition</i>	<i>page</i> xviii
<i>Preface to the second edition</i>	xx
<i>Preface to the first edition</i>	xxi
1 Amplification and the transistor	1
1.1 Amplification	1
1.2 The transistor as an amplifying device	2
1.3 Introduction to solid-state devices	6
1.3.1 General	6
1.3.2 Semiconductors	6
1.3.3 Electrons and holes	7
1.3.4 Extrinsic conductivity	9
1.3.5 Majority and minority carriers	11
1.3.6 Compensation	11
1.3.7 The pn junction	11
1.3.8 Biased pn junction	12
1.3.9 Avalanche breakdown	14
1.3.10 Junction capacitance and varactor diodes	15
1.4 The transistor	16
1.4.1 Introduction	16
1.4.2 Transistor action	16
1.4.3 Second-order effects	18
1.4.4 Collector-base leakage current	20
1.4.5 npn and pnp transistors	20
1.4.6 Optoelectronic devices	20
1.5 Testing transistors	22

viii *Contents*

1.6	Voltage amplification	23
1.6.1	Introduction	23
1.6.2	Load resistor	23
1.6.3	Working point and bias	24
1.6.4	Coupling capacitors	25
1.6.5	Stabilizing the operating point	26
1.6.6	Stabilized voltage amplifier	28
1.6.7	Measurement of voltage gain	29
1.7	Saturated operation	30
2 The field-effect transistor		34
2.1	Introduction	34
2.2	The JFET	34
2.2.1	Construction	34
2.2.2	JFET operation	35
2.3	The MOSFET	36
2.4	FET transfer characteristics	39
2.5	Transconductance	39
2.6	A voltage amplifier using a FET	41
2.7	MOSFETs in practice	42
2.7.1	High input resistance amplifier	42
2.7.2	Power applications	43
2.7.3	Static precautions	43
2.7.4	Integrated circuits	43
3 Thermionic valves and the cathode-ray tube		44
3.1	Introduction	44
3.2	Thermionic emission	44
3.3	The thermionic diode	45
3.4	The triode valve	47
3.5	Cathode developments	49
3.6	The triode voltage amplifier	50
3.7	The tetrode and pentode	52
3.8	The pentode voltage amplifier	53
3.9	Valve switching circuits	54
3.10	The cathode-ray tube	55
3.10.1	Construction and operation	55
3.10.2	Screen phosphors	57

Contents

ix

4 Negative feedback	59
4.1 Introduction to feedback principles	59
4.2 Negative feedback in electronics	60
4.3 An amplifier with feedback	61
4.4 Negative feedback and frequency response	63
4.5 Non-linear distortion	64
4.5.1 Introduction	64
4.5.2 Harmonic distortion measurement	65
4.5.3 Intermodulation distortion measurement	66
4.5.4 Calculation of r.m.s. distortion products	67
4.5.5 Distortion and negative feedback	67
4.6 Instability and negative feedback	70
4.7 Current feedback	70
4.8 Experiments with negative feedback	72
5 Impedance matching	76
5.1 Introduction	76
5.2 Input impedance	76
5.3 Measurement of input impedance	77
5.4 Output impedance	79
5.5 Measurement of output impedance	80
5.6 Impedance matching for optimum voltage transfer	81
5.7 Impedance matching for optimum power transfer	83
5.8 Impedance matching for optimum current transfer	85
5.9 Impedance matching for minimum amplifier noise	85
5.9.1 Signal-to-noise ratio	85
5.9.2 Thermal noise	86
5.9.3 Noise in transistors	87
5.9.4 Noise figure	87
5.9.5 Noise figure and the bipolar transistor	90
5.9.6 Practical low-noise amplifier	92
5.9.7 Noise in FETs	93
5.10 Introduction to impedance changing	94
5.11 Impedance changing by transformer	95
5.12 The emitter follower	97
5.12.1 Emitter follower circuit design	97
5.12.2 a.c. signals in the emitter follower	99
5.12.3 Emitter follower input impedance	101
5.12.4 Emitter follower output impedance	102

x *Contents*

5.12.5	Darlington pair	103
5.12.6	Improved d.c. stability	104
5.12.7	Feeding long cables	106
5.13	The source follower	106
5.13.1	Circuit design	106
5.13.2	Input and output impedance of the source follower	108
5.13.3	Improved operating point for the source follower	109
5.14	Voltage and power gain	111
5.15	Negative feedback and output impedance	111
5.16	Negative feedback and input impedance	112
5.17	Power output of emitter followers	114
5.17.1	Load current and quiescent current	114
5.17.2	Class B and class AB push–pull operation	114
5.17.3	A typical audio power amplifier	119
5.17.4	High-power FETs	121
5.17.5	IC power amplifiers	122
6	Semiconductor device characteristics	123
6.1	Introduction	123
6.2	pn junction characteristics	123
6.3	Bipolar transistor input and transfer characteristics	126
6.4	Introduction to output characteristics	129
6.5	Collector characteristics	129
6.5.1	Measurement method and results	129
6.5.2	Load line and saturation	133
6.5.3	Maximum ratings	134
6.6	FET drain characteristics	136
6.7	The FET as a voltage-controlled resistor	138
6.8	Common-emitter equivalent circuit and amplifier gain	140
6.9	FET common source equivalent circuit and amplifier gain	142
6.10	Variation in FET transconductance	144
7	Amplification at high frequencies	146
7.1	High-frequency considerations	146
7.2	High frequencies and the bipolar transistor	147
7.2.1	Base–emitter capacitance	147
7.2.2	Transition frequency	148
7.2.3	Variation of transition frequency with collector current	149
7.3	Transistor circuit performance at high frequencies	151

Contents

xi

7.3.1	Voltage amplifiers and Miller effect	151
7.3.2	Common-emitter amplifier at high frequencies	153
7.3.3	High frequencies and the emitter follower	155
7.4	FETs at high frequencies	156
7.5	Special circuits for high frequencies	158
7.5.1	General	158
7.5.2	Common-base amplifier	158
7.5.3	The common-gate circuit	162
7.5.4	The cascode circuit	162
7.5.5	The dual-gate MOSFET	164
7.6	Wideband high-frequency amplifiers	165
7.7	Amplitude and phase response of low-pass filter	167
8 Low-frequency signals, d.c. and the differential amplifier		174
8.1	Introduction	174
8.2	Low-frequency attenuation	175
8.3	Features of d.c. amplifiers	178
8.3.1	Design	178
8.3.2	Input bias current	180
8.3.3	Drift	180
8.4	The differential amplifier	181
8.4.1	Basic circuit	181
8.4.2	Voltage gain	182
8.4.3	Common-mode rejection and drift reduction	186
8.4.4	Balanced output	190
8.4.5	Voltage-controlled amplifier	191
8.5	IC amplifiers	192
8.6	Electronic thermometer	193
8.7	Noise rejection with the differential amplifier	194
8.8	Simple physiological amplifier	196
8.9	Chopper d.c. amplifiers	197
9 Power supplies and power control		200
9.1	Power sources	200
9.2	Rectification of a.c.	201
9.3	Smoothing	204
9.3.1	General	204
9.3.2	Ripple	205
9.4	Load regulation	207

xii *Contents*

9.5	Rectifier and capacitor ratings	207
9.6	Voltage-multiplying circuits	208
9.7	Filter circuits	210
9.8	Decoupling	211
9.9	Variable voltage supplies	212
9.9.1	Potentiometer	212
9.9.2	The emitter follower in power supply circuits	213
9.10	Voltage stabilizers	215
9.10.1	General	215
9.10.2	Basic Zener diode stabilizer	215
9.10.3	Stabilization ratio	217
9.10.4	Limitations of simple Zener diode circuit	218
9.10.5	Dealing with high load currents	222
9.10.6	Improved stabilization using an error amplifier	223
9.10.7	Stabilizers and ripple reduction	225
9.10.8	The Zener diode as a precision voltage reference	226
9.10.9	The bandgap voltage reference	227
9.10.10	Short-circuit protection	228
9.10.11	IC regulators	230
9.11	Transistor heat dissipation	233
9.11.1	Heat sinks	233
9.11.2	Electrical insulation	233
9.11.3	Thermal resistance	234
9.12	Switch-mode power supplies	235
9.12.1	d.c. to d.c. conversion	235
9.12.2	Direct mains line switching supplies	238
9.13	Power control with thyristors, transistors and triacs	238
9.13.1	Introduction to the thyristor	238
9.13.2	Construction and operation of the thyristor	239
9.13.3	Power control with transistors	242
9.13.4	The triac and its applications	242
10	Pulse handling and time constants	248
10.1	Introduction	248
10.2	'Squaring' a waveform	249
10.3	Fourier analysis	250
10.4	Charging, discharging and time constants	251
10.5	Ringing	256

<i>Contents</i>	xiii
10.6 Time constants and transistors	257
10.7 Coupling capacitors in pulse circuits	258
10.8 Clamp diode	260
10.9 Coupling capacitor time constant	261
10.10 Differentiation and integration	263
10.11 Electronic calculus	268
10.12 The charge pump ratemeter	268
10.13 Pulse clipping	269
11 Integrated circuit analogue building bricks	272
11.1 Introduction	272
11.2 The operational amplifier	273
11.2.1 Simplifying assumptions	273
11.2.2 Input bias current and offset voltage	273
11.2.3 Offset null circuit	277
11.3 Practical circuit details	278
11.4 The non-inverting amplifier	279
11.4.1 Basic d.c. amplifier	279
11.4.2 Use of coupling capacitors	281
11.4.3 a.c. amplifier with single power supply	282
11.5 The inverting amplifier	284
11.5.1 Introduction	284
11.5.2 The virtual earth	285
11.5.3 a.c. operation of inverting amplifier	286
11.6 The differential feedback amplifier	286
11.7 The operational adder	287
11.8 The operational integrator	290
11.8.1 Basic circuit	290
11.8.2 Offset in an integrator	292
11.8.3 Accuracy and integration time	293
11.8.4 Ramp generator	294
11.8.5 Charge-sensitive amplifier	296
11.9 The operational differentiator	298
11.10 Current-to-voltage converter	300
11.11 Bandwidth of op amp circuits	301
11.12 Rise time and slew rate	303
11.13 Power supplies	305
11.13.1 Supply voltage and output capability	305
11.13.2 Power supply stability and ripple requirements	305

xiv *Contents*

11.14 Active filters	306
11.14.1 General	306
11.14.2 Low-pass filters	306
11.14.3 High-pass filters	316
11.14.4 Band-pass filters	317
11.14.5 Tone controls	322
11.15 Logarithmic amplifiers	323
11.16 Precision rectifiers	327
11.17 The differential comparator	329
11.17.1 Introduction	329
11.17.2 Hysteresis by positive feedback	331
11.18 Op amp data	332
11.19 Analogue multiplier	332
11.20 Analogue divider	336
11.21 Analogue simulation	338
11.21.1 Introduction	338
11.21.2 Damped resonant system (harmonic oscillator)	338
11.22 State-variable filter	341
11.23 Switched-capacitor filter	341
12 Positive feedback circuits and signal generators	344
12.1 Positive feedback	344
12.2 Sinusoidal oscillators	345
12.2.1 The phase-shift oscillator	345
12.2.2 The Wien bridge oscillator	348
12.2.3 Quadrature oscillator	351
12.2.4 LC tuned oscillator	352
12.3 Crystal oscillators	353
12.4 The bistable multivibrator	355
12.5 The astable multivibrator	356
12.6 The monostable multivibrator	360
12.7 The binary counter	361
12.8 The Schmitt trigger	362
12.9 Voltage-controlled oscillator	364
12.10 Phase-locked loop	364
12.10.1 Basic outline	364
12.10.2 Phase comparator	365
12.10.3 Practical phase-locked loop	366

Contents

xv

13 Digital logic circuits	369
13.1 The digital world	369
13.2 Logic functions and gates	370
13.3 Electronic gates	372
13.4 Input and output conditions	374
13.5 Circuit classification	375
13.6 Truth tables	375
13.7 Simple combinations of gates	376
13.8 Addition of binary numbers	377
13.9 Integrated circuit logic	380
13.9.1 Introduction	380
13.9.2 TTL	380
13.9.3 CMOS	382
13.10 Sequential logic – flip-flops and memories	385
13.10.1 Introduction to flip-flops	385
13.10.2 Clocked <i>RS</i> flip-flop	388
13.10.3 <i>D</i> -type flip-flop	389
13.10.4 <i>JK</i> flip-flop	390
13.10.5 Master–slave and edge-triggered flip-flops	390
13.11 Registers	393
13.11.1 Memory registers	393
13.11.2 The shift register	393
13.12 Binary counting	396
13.12.1 Introduction	396
13.12.2 Reset inputs and counting sequence	398
13.12.3 The BCD counter	399
13.12.4 Cascading BCD counters	401
13.12.5 Synchronous counting	402
13.13 Decoders and displays	403
13.13.1 Direct decoding – decimal and hexadecimal	403
13.13.2 Seven-segment displays and decoders	406
13.13.3 The 74LS75 bistable latch	408
13.13.4 Multiplexed displays	409
13.14 The Schmitt trigger 7413	411
13.15 Monostables and timers	413
13.15.1 General	413
13.15.2 The 74121 monostable	413
13.15.3 The 555 timer	416
13.16 Data multiplexers	419

xvi *Contents*

13.17	Interconnection of logic chips	421
13.17.1	General precautions	421
13.17.2	Gate connections and operation	422
13.17.3	Power supplies	423
13.18	Emitter-coupled logic	424
13.19	Gate arrays	424
13.20	Programmable logic devices	425
13.21	Switching analogue signals with CMOS	426
14	Microcomputer circuits and applications	428
14.1	Computer operations	428
14.2	Electronic arithmetic	428
14.2.1	Addition	428
14.2.2	Subtraction	430
14.2.3	Binary multiplication and division	434
14.3	Bits, bytes and nibbles	436
14.4	Data buses	436
14.5	Storage and memories	440
14.5.1	Magnetic and optical data storage	440
14.5.2	Random access memory (RAM)	440
14.5.3	ROM, EPROM & E ² PROM	443
14.6	The microcomputer	444
14.7	Software	447
14.7.1	Instruction sequence	447
14.7.2	Machine code	447
14.7.3	Starting the program running	449
14.7.4	Entering and running machine code directly	450
14.7.5	Assembly code	451
14.7.6	High-level languages	454
14.8	Input and output to microcomputers	456
14.8.1	Address decoding	456
14.8.2	Output port	458
14.8.3	Input port	460
14.8.4	Practical ports for the PC	460
14.9	I/O experiments using the Acorn BBC Micro	462
14.10	Exploring the CPU	464
14.11	Processor digressions	467
14.11.1	Interrupts	467
14.11.2	Direct memory access (DMA)	471

Contents

xvii

14.12 Digital signal processing (DSP)	471
14.13 Digital filters	472
14.14 Digital to analogue conversion	473
14.15 Analogue to digital conversion	475
14.15.1 Some basic ADC hardware	475
14.15.2 Sample/hold circuit	477
14.15.3 Quantization noise and dither	477
14.15.4 Sampling frequency	479
14.15.5 Delta-sigma (oversampling) data conversion	481
Appendix 1 Component identification	486
Appendix 2 Transistor selection	490
Appendix 3 Op amp data	492
Appendix 4 Digital IC connections	494
Appendix 5 Interfacing to the PC	500
<i>Bibliography</i>	508
<i>Index</i>	511