

Contents

1

Review of Elementary Circuit Theory 1

1-1	Introduction	1
1-2	Electrical quantities	2
1-3	Constant and variable voltages and currents	3
1-4	Voltage and current sources; Kirchhoff's laws	4
1-5	Resistances in series and parallel	6
1-6	Network analysis	7
1-7	The Wheatstone bridge circuit	10
1-8	The π to T (delta to star) transformation	11
1-9	Network theorems	13

2

Responses of Electric Circuits 19

2-1	The basic circuit equations	19
2-2	Response of LR and RC series circuits	21
2-3	Response of LR circuit to an alternating voltage source	25
2-4	Techniques for use with steady-state alternating currents and voltages	27
2-5	Circuit equations and network theorems applied to steady-state ac quantities	35
2-6	Effect of frequency on Z and Y ; resonance	36
2-7	Equivalent circuits	40
2-8	Mutual inductance; transformers	41
2-9	Attenuation and phase characteristics of simple two-terminal-pair networks; the decibel	44
2-10	Parameters and equivalent circuits for a linear, two-terminal-pair network	49
2-11	Network properties in terms of network parameters	52

3

Thermionic and Semiconductor Diodes 56

3-1	Introduction	56
3-2	Devices and circuits	56
3-3	The thermionic diode	58
3-4	Electron emission; practical cathodes	59
3-5	Space-charge relations in the diode	61
3-6	The gas-filled thermionic diode	62
3-7	Conductors, semiconductors, and insulators	63
3-8	Conduction processes in semiconductors	64
3-9	<i>p</i> -type and <i>n</i> -type semiconductors	65
3-10	Energy band picture for crystalline semiconductors	66
3-11	The semiconductor junction diode	69
3-12	Junction diode voltage-current relation	73
3-13	Diode ratings	76

4

Vacuum Tubes as Circuit Elements 78

4-1	Electronic circuits	78
4-2	Graphical analysis of a diode circuit	79
4-3	Circuit model for the diode	80
4-4	Separation of dc and incremental components of e and i	82
4-5	Grid control of space-charge-limited current, the triode	84
4-6	Graphical analysis of a triode amplifier	88
4-7	Amplifier design by the load-line method	92
4-8	Ideal output filter; ideal output transformer	94
4-9	Triode parameters and equivalent circuits for small-signal operation	96
4-10	The common-cathode amplifier	99
4-11	The common-plate (cathode-follower) amplifier	100
4-12	The common-grid amplifier	102
4-13	The tetrode, pentode, and beam power tube	103

5

Physical Principles of Semiconductor Devices 111

5-1	The junction transistor	111
5-2	Experimental evidence of hole motion	113
5-3	Transistor characteristics with the common-base connection	115
5-4	Internal transistor action	117
5-5	Energy band picture of the <i>npn</i> transistor	118
5-6	Early effect; punch-through; breakdown	120
5-7	Common emitter characteristics	121
5-8	Effect of temperature; collector dissipation rating	123
5-9	Small signal parameters based on internal behavior	125
5-10	The <i>pnpn</i> silicon controlled rectifier (<i>SCR</i>)	127
5-11	Additional types of transistor	129

6

Small-Signal Analysis of Transistor Amplifiers 133

6-1	Introduction	133
6-2	Equivalent- <i>T</i> circuits for the common-base, common-emitter, and common-collector connections	134
6-3	Gain and network properties of the common-emitter amplifier	138
6-4	The common-base amplifier	142
6-5	The common-collector amplifier	144
6-6	Further comparison of the basic amplifiers and some practical considerations	146
6-7	Equivalent circuits in terms of <i>h</i> parameters	150
6-8	Low frequency <i>h</i> parameters from transistor characteristics	151
6-9	Amplifier calculations using <i>h</i> parameters	153
6-10	Approximate calculations using <i>h</i> parameters	155
6-11	Determination of transistor parameters	156
6-12	Measurement of the small-signal short-circuit forward-current gain cutoff frequency	157

7**Voltage Amplifiers 161**

7-1	Introduction	161
7-2	Class A, class AB, class B, and class C operation	162
7-3	The amplifier as a network element; cascade connection	162
7-4	Q -point determination in triode circuits	164
7-5	The effect of the cathode bias circuit on voltage gain	166
7-6	The effect of an output filter on the voltage gain	168
7-7	The effect of stray capacitances on gain and input impedance of tube amplifiers	170
7-8	RC -coupled pentode amplifier stage	173
7-9	Frequency response of RC -coupled amplifier	174
7-10	Bias circuits for transistor amplifiers; stability	178
7-11	Bias stability analysis	182
7-12	Transistor behavior at higher frequencies	185
7-13	Common-emitter circuit at higher frequencies	187
7-14	The hybrid- π equivalent circuit	188
7-15	Common-emitter stages in cascade	190

8**Power Amplifiers 200**

8-1	Introduction	200
8-2	Class A power amplifier	201
8-3	Large-signal analysis of a class A common-emitter stage	203
8-4	Harmonic distortion in the output wave	205
8-5	Balanced amplifier; class B operation	207
8-6	Class C amplifier	210
8-7	Transistor in the switching mode; ON-OFF control	212
8-8	Controlled rectifier as a power amplifier	216
8-9	Magnetic amplifier	218

9**Feedback Theory; Feedback in Amplifiers 224**

9-1	Introduction	224
9-2	Basic feedback analysis	225

9-3	Voltage (series-parallel) feedback	226
9-4	Effect of feedback on input and output impedances	228
9-5	Effect of negative voltage feedback on noise and distortion	230
9-6	Current (series-series) feedback	231
9-7	Shunt (parallel-parallel) feedback	232
9-8	Feedback in transistor amplifiers	233
9-9	Gain versus frequency	239
9-10	Stability considerations	242

10

Gaseous Diodes and Triodes 250

10-1	Electrical discharges in gases	250
10-2	Mechanism of gaseous conduction	251
10-3	Breakdown voltage; glow and arc discharges and tubes	252
10-4	The gas-filled triode (thyatron)	256
10-5	Grid current in thyatrons; shield-grid thyatron	258
10-6	Phase-shift circuit for thyatron control	259
10-7	The ignitron	260

11

Rectifier Circuits, Filters and dc Power Supplies 263

11-1	Half-wave and full-wave rectifier circuits	263
11-2	Elementary polyphase rectifier circuits	266
11-3	Simple inductor or capacitor filters	270
11-4	Voltage doubler circuits	273
11-5	Smoothing filters	274
11-6	Analysis of inductor-input filter	275
11-7	Diode voltage regulator circuits	276
11-8	Voltage regulators using amplifiers	279

12**Oscillator and Inverter Circuits 288**

12-1	Introduction	288
12-2	Thyratron sawtooth generator	288
12-3	Negative resistance oscillators	290
12-4	RC feedback oscillator circuits	292
12-5	LC feedback oscillator circuits	297
12-6	LC feedback power oscillator analysis	301
12-7	Other oscillator circuits	307
12-8	Inverter circuits	308

13**Modulation, Demodulation, and Related Topics 312**

13-1	Introduction	312
13-2	Amplitude modulation	313
13-3	Examples of AM modulators and detectors	315
13-4	Square-law modulation	318
13-5	Frequency modulation and detection	319
13-6	Analysis of an FM wave	323
13-7	Superheterodyne receivers; frequency converter (mixer)	325
13-8	Switch modulators	329
13-9	Phase discriminator; phase-sensitive detector	330

14**dc Amplifiers and the Analog Computer 337**

14-1	Elementary dc amplifiers	337
14-2	Differential or difference amplifiers	340
14-3	Instrument amplifiers based on modulation; chopper amplifier	347
14-4	Chopper-stabilized wideband dc amplifier	349
14-5	Analog computation	352

14-6	Operational amplifiers	354
14-7	Operational amplifier in instrumentation	357
14-8	Example of an analog computer solution	358
14-9	Additional computer elements	361
14-10	Analog computer techniques	363

15

Servo Systems; Regulators 367

15-1	Introduction	367
15-2	Feedback versus nonfeedback systems	368
15-3	A second-order servo	371
15-4	Response of the second-order servo to a ramp function	375
15-5	Second-order servo with velocity feedback	376
15-6	Servo with error-rate damping	378
15-7	Servo with error-rate plus integral control	379
15-8	Limitations of the differential equation approach; the frequency-response approach	380
15-9	Transfer functions	382
15-10	Open-loop and closed-loop transfer functions; stability	385
15-11	A compensated servo	388
15-12	Servo components and systems	392
15-13	A generator voltage regulator	394

16

Wave Forming and Shaping; Pulse Generators 401

16-1	Introduction	401
16-2	Pulse response of the series RC circuit	401
16-3	The series RC circuit as an approximate integrator or differentiator	404
16-4	Compensated attenuator	405
16-5	Clipping and clamping circuits	407
16-6	Gate circuits	410

16-7	Block diagram of a pulse counter	411
16-8	Bistable multivibrator (flip-flop)	411
16-9	Collector triggering circuit using steering diodes	415
16-10	Astable (free-running) multivibrator	418
16-11	Nonlocking astable MV ; synchronizing	420
16-12	Monostable (one-shot) multivibrator	422
16-13	The Schmitt trigger circuit	424
16-14	Time delays in a transistor switch	426
16-15	Further discussion and analysis of multivibrator and trigger circuits	430
16-16	The blocking oscillator	433
16-17	Pulse response of amplifiers	435
16-18	Triggered linear sweep generator	439
16-19	The Miller integrator sweep circuit; bootstrap circuit	440

17

***Logic and Counting Circuits* 447**

17-1	Introduction	447
17-2	The binary number system	448
17-3	Elementary Boolean algebra	449
17-4	Diode logic circuits: AND, OR	453
17-5	Examples of transistor logic circuits: NOT, NOR	458
17-6	Binary scalars	459
17-7	Diode matrix for decimal count readout	462
17-8	Decimal counter	465
17-9	Special counting devices	466
17-10	Pulse rate meter (diode pump)	468
17-11	Counters and their application	470

18

***Transducers* 476**

18-1	Introduction	476
18-2	Classification of transducers	477

18-3	Examples of displacement transducers	479
18-4	Measurement of velocity, acceleration, pressure	483
18-5	Analysis of the response of the mass-spring transducer to harmonic excitation	485
18-6	Transducers for temperature measurement	488
18-7	Photosensitive transducers	490
18-8	Technical aspects of photodevice applications	494
18-9	Transducers for ionizing radiations	498

19

***Electronic Instruments* 504**

19-1	Introduction	504
19-2	Conventional test instruments	504
19-3	Electronic voltmeters	507
19-4	Interpretation of electronic voltmeter readings	512
19-5	Electronic self-balancing potentiometer; <i>X-Y</i> recorder	514
19-6	Potentiometer circuits	516
19-7	Cathode-ray oscilloscope	518
19-8	Phase meter	526
19-9	Instruments based on the Hall effect	527
19-10	Electrometer tubes and electrometer circuits	529

20

***Electrical Noise* 536**

20-1	Introduction	536
20-2	Reduction of stray voltages	536
20-3	Thermal noise	539
20-4	Circuit calculations involving thermal noise	542
20-5	Definitions of noise temperature, noise ratio, and noise figure	545
20-6	Device noise	548
20-7	Measurement of noise figure	551

21**Data Acquisition, Transmission,
Recording, and Processing;
Telemetry 555**

21-1	Introduction	555
21-2	Examples of data systems	556
21-3	Some elements of data system theory	558
21-4	Data system requirements	566
21-5	Analog recording systems	568
21-6	Response of the galvanometer recorder	575
21-7	Analog-digital converters	579
21-8	Digital recording systems	581
21-9	Digital-analog converters	582
21-10	Multiplexing systems; telemetry	584
21-11	Digital computers	587
21-12	Digital plotters	589

A**Physical Constants, Abbreviations
for Units, and Multiplying Factors 595**

A-1	Physical constants	595
A-2	Abbreviations for units	595
A-3	Multiplying factors and prefixes	595

B**Selected Device Data and
Characteristics 597**

Data on the following tubes: 6X4, 6AU6A, 6L6GC,
12AU7A, and 12AX7A, and on the following transistors:
2N708, 2N1100, 2N1302 through 2N1309, 2N1613,
and 2N2953

C***Transformations among the Circuit Parameters 608***

- | | | |
|-----|----------------------------------------------------------------------------------------------------------|-----|
| C-1 | Relations among z , y , and h parameters | 608 |
| C-2 | Approximate conversion relationships among the h parameters and the equivalent- T circuit parameters | 609 |

D***Outline of the Fourier Analysis of Periodic Functions, with an Application to Electric Circuit Calculations 610*****E*****Transmission Lines; Delay Lines 614***

- | | | |
|-----|-----------------------------------------------------------------------------|-----|
| E-1 | Introduction | 614 |
| E-2 | Waves on transmission lines; speed of propagation; characteristic impedance | 615 |
| E-3 | Reflections of waves on transmission lines | 619 |
| E-4 | Electromagnetic delay lines | 621 |
| E-5 | Examples of delay line application | 622 |

Index 625