

PHYS-3360/ AEP-3630
LABORATORY MANUAL
2019-2020

E. J. Kirkland and R. Littauer
School of Applied and Engineering Physics and
Physics Department
Cornell University

June 25, 2019

Contents

1	INTRODUCTION (10 exp.)	1
1.1	Voltage Signals and Ground	1
1.2	Measuring Voltages and Rise Time	2
1.3	Using the Oscilloscope	4
1.3.1	Vertical	4
1.3.2	Horizontal	6
1.3.3	Triggering	6
1.3.4	Input Probes	8
1.4	Ideal Voltage and Current Sources	9
1.5	Resistors	10
1.6	Kirchhoff's Laws	12
1.7	Superposition	13
1.8	Capacitors	14
1.9	Circuit Assembly	16
1.10	Waveshaping by R-C Circuits	17
1.11	Low-Pass Filter	18
1.12	High-Pass Filter	21
1.13	Source Impedance (or Resistance)	23
1.14	Thevenin's Theorem	25
1.15	Norton's Theorem	29
1.16	Source Impedance and Capacitive Loads	30
1.17	Practice Problems	31
2	THE OPERATIONAL AMPLIFIER (6 exp.)	33
2.1	Introduction	33
2.2	The Decibel	35
2.3	Manufacturers' Data Books and Spec-Sheets	36
2.4	Connecting the Power Supplies	37
2.5	Small-Signal Amplification and Input Offset Voltage	38
2.6	The Overdriven Amplifier or Comparator	40
2.7	The Ideal Op-Amp	43
2.8	Positive Feedback and the Schmitt Trigger Circuit	43

2.9	Free-Running (Astable) Multivibrator or Oscillator	46
2.10	Single-Supply Operation	48
2.11	Typical Values of Some Op-amp Parameters	49
2.12	Practice Problems	50
3	SINUSOIDAL SIGNALS (3 exp.)	51
3.1	Phasor Representation	51
3.2	Complex Notation	52
3.3	Complex Impedance	53
3.4	Working with Complex Numbers	53
3.5	The Inductor	54
3.6	The Capacitor	55
3.7	Combinations of Elements	56
3.8	The Transfer Function and Bode Plots	58
3.9	High-Pass R-C Filter	59
3.10	Low-Pass Filter	61
3.11	Bode Plots, Poles and Zeros	62
3.12	A Bandpass Filter	65
3.13	Computer Aided Design and Analysis	68
3.14	Fourier Analysis. The Frequency Domain	70
3.15	R-C Networks in the Frequency Domain	73
3.16	Differentiation and Integration—the Time-Domain View	74
3.17	A Note on Dimensions	75
3.18	Practice Problems	75
4	NEGATIVE FEEDBACK CIRCUITS (9 exp.)	79
4.1	General Principles	79
4.2	Differential and Common-Mode Signals	82
4.3	The Voltage Follower	83
4.4	Noninverting Amplifier	84
4.5	The Inverting Configuration	84
4.6	The Virtual-Ground Point: Current Control	87
4.7	Non-Ideal Op-Amp Properties	88
4.8	Summing with Op-Amps	90
4.9	Differential Amplifier	91
4.10	Time Integration Using an Op-Amp	92
4.11	Active Filters	94
4.12	Integration and Bias Currents	96
4.13	Time Differentiation using Op-amps	98
4.14	Nonlinear Operations	100
4.15	Stability	101

4.16	Stability Problems in Voltage Followers	102
4.17	Op-amp Summary	104
4.18	Practice Problems	104
5	DIODES (6 exp.)	109
5.1	Ideal Diode	109
5.2	The Silicon Junction Diode	109
5.3	The Diode Equation	111
5.4	Diode Ratings	112
5.5	Zener Diodes	113
5.6	Measuring the I-V Curve of a Diode	114
5.7	Rectification	116
5.7.1	Half-Wave Rectification	117
5.7.2	Full-wave rectification with center-tapped transformer	117
5.7.3	Full-wave bridge rectification	118
5.7.4	Voltage Doubler	119
5.7.5	Filter Capacitor	119
5.8	Diode Circuit Notes	121
5.9	Clipping Circuits (Limiters)	122
5.10	AC Coupling (Level Shifting), DC Restoration	123
5.11	Pickoff Circuits, Pulse Stretching	125
5.12	Waveshaping with Circuits Containing Diodes	126
5.13	Diodes in the Operational Configuration	127
5.14	Incremental Diode Resistance	130
5.15	SOME DIODE CHARACTERISTICS	132
5.16	Practice Problems	132
6	THE BIPOLAR JUNCTION TRANSISTOR(BJT), (9 exp.)	137
6.1	Basic Mechanism	137
6.2	Common-Emitter Transistor Characteristics	140
6.3	Circuit Model for the Bipolar Transistor	143
6.4	The Load Line	143
6.5	The Saturating Inverter	144
6.5.1	Cutoff	145
6.5.2	Active	146
6.5.3	Saturation	146
6.6	DC bias and the Q-point	149
6.7	Voltage Control and Transconductance	150
6.8	The Emitter Follower	152
6.9	Emitter Bias	157
6.10	Constant-Current Source	159

6.11	Common Emitter Amplifier	160
6.12	Darlington Pairs	162
6.13	Emitter-Coupled Pair	162
6.14	Power in Transistor Circuits	165
6.15	Transistor Parameters	169
6.16	Practice Problems	169
7	MOSFET TRANSISTORS (5 exp.)	175
7.1	MOSFET Structure and Circuit Symbols	176
7.2	N-Channel MOSFET Function	177
7.3	N-MOSFET Current-Voltage Characteristics	178
7.3.1	Ohmic or Triode Region	178
7.3.2	Saturation Region	179
7.3.3	Measurement	180
7.4	The MOSFET Amplifier	184
7.4.1	One Transistor MOSFET Amplifier	184
7.4.2	Two Transistor Differential Amplifier	188
7.5	Power MOSFETS	191
7.6	Digital Signals	191
7.7	JFET's and Depletion Mode MOSFET's	193
7.8	Practice Problems	195
8	DIGITAL GATES AND COMBINATORIAL LOGIC (7 exp.)	197
8.1	Digital Signals	197
8.2	Logic Operations	198
8.2.1	Negation or Inversion $X = \bar{A}$	198
8.2.2	AND $C = A \cdot B = AB$	199
8.2.3	OR (Inclusive OR) $C = A + B$	199
8.2.4	NAND, NOR	200
8.2.5	Exclusive-OR (XOR) $C = A \oplus B$	200
8.2.6	Multiple Inputs	201
8.3	High Speed CMOS Logic (The 74HC00 Series)	201
8.4	Logic Functions and Boolean Algebra	204
8.5	DeMorgan's Theorem	207
8.6	Addition of Binary Numbers	208
8.7	Multiplexers and Decoders	210
8.8	Analog Transmission Gate	212
8.9	CMOS Circuitry	214
8.10	Schmitt Trigger Inputs	219
8.11	Tri-State Outputs	220
8.12	Simplifying Logic with Karnaugh Maps	220

8.13 Legacy TTL and LS-TTL Logic	222
8.14 Practice Problems	225
9 SEQUENTIAL CIRCUITS (7 exp.)	227
9.1 Introduction	227
9.2 R-S Flip-Flop	227
9.3 Propagation Delay	230
9.4 D Flip-Flop	231
9.5 J-K Flip-Flops	233
9.6 Synchronous Systems	235
9.7 Registers	236
9.8 Counters	239
9.9 Initialization	242
9.10 Practice Problems	243
10 TIMING AND TRANSDUCERS (4 exp.)	247
10.1 RC Timing	247
10.2 The 555 Timer IC	248
10.3 Monostable Operation of the 555 (One Shot)	249
10.4 Astable Operation of the 555 (Oscillator)	250
10.5 74xx00 Family One-Shots	251
10.6 Clocks	253
10.7 Distance Measurement with Ultrasonic Transducers	254
10.8 Practice Problems	257
11 LABORATORY COMPUTERS (5 exp.)	259
11.1 Computer System Description	260
11.1.1 Input and Output Connections (Buses)	261
11.1.2 Lab Computer	262
11.2 Microprocessor Evolution	263
11.3 Programming	265
11.4 Hexadecimal Numbers	266
11.5 The Microsoft Visual C/C++ Programming Environment	266
11.6 A Sample Program in C/++	267
11.7 Programming in Assembly Language	269
11.8 A Sample Program in Assembly Language	272
11.9 The Data Acquisition Port (DAQ)	273
11.10 Reading Data Into Computer From the Outside World	277
11.11 Writing Data Out of Computer	278
11.12 Computer I/O Speed	281
11.13 External Synchronization	282
11.14 Listing of ni.h	283

11.15 Practice Problems	285
12 COMPUTER DATA ACQUISITION (7 exp.)	287
12.1 Digital-to-Analog Conversion	287
12.2 The Ramp Generator	289
12.3 Analog to Digital Conversion, the Digital Voltmeter	291
12.4 Digitization by Successive Approximations	293
12.5 The Digital Sampling Scope	295
12.6 Signal Averager (Box-Car Integrator)	301
12.6.1 Noise Generator	303
12.7 Practice Problems	306
A Data Recording and Laboratory Notebooks	309
B Laboratory Equipment	313
C Manufacturers and Distributors	315

Appendix B

Laboratory Equipment

Each lab station is set up to accommodate two people at one time and should have the following equipment (or its equivalent):

1. Oscilloscope (min. of Tektronix TDS-1002, dual channel, 60 MHz, digital storage, 2 GS/s)
2. Function generator (sine, square and triangle waves, 0 to 2 MHz, B&K 3022)
3. Two variable power supplies (0 to ± 15 volts, about 250 mAmp)
4. Solderless breadboard for circuit assembly
5. Assorted 1/4 Watt resistors (10 Ohms to 10 MegOhms)
6. Assorted capacitors (10 pfd to 220 μ F)
7. Assorted wire (solid 22 guage, BNC cables), and tools (needle nose pliers, wire cutter, wire striper, and small screwdriver for scope probe adjustments)
8. Computer with data acquisition board with digital I/O, DAC, ADC (Nat. Instr. USB-6008) and C++ compiler.
9. Other semiconductor components (transistors, diodes, integrated circuits, etc.) obtained as needed (some listed below).

op-amps: 741, 3140

instrumentation amplifier: AD622

diodes: 1N914 (signal), 1N4007 (power), 1N4735 (zener)

transistors: 2N3906 (NPN), 2N3906 (PNP), 2N7000 (n-chan. MOSFET)

high speed CMOS: 74HC00 (NAND), 74HC02 (NOR), 74HC04 (inverter), 74HC08 (AND), 74HC14 (Schmit trigger inverter), 74HC32 (OR), 74HC74 (D flip flop), 74HC86 (XOR), 74HC161 (4 bit synch. counter), 74HC164 (8 bit par. out shift reg), 74HC194 (4 bit shift left/right), 74HC221 (dual one-shot), 74HC240 (octal 3-state invert. buffer) 74HC283 (4 bit adder), 74HC4066 (quad analog switch)

Misc.: 6.3VAC CT transformer, 555 (timer), 7-segment LED display, 40kHz acoustic transducer, small radio and audio speaker

Appendix C

Manufacturers and Distributors

Electronics components, from discrete components like resistors and capacitors to sophisticated integrated circuits are manufactured by a variety of different companies. However, in most cases, you do not buy the components directly from the manufacturers. Instead you purchase the components from a distributor. Distributors range from large scale industrial suppliers who will only sell components in large quantities to other companies to small mail order companies that will sell small quantities of components to individuals.

In most cases you must get the specifications for the components and decide what you want before contacting the distributor. This information is available in the form of data books from the manufacturer (discussed more in chapter 2) or in many cases can be found on web sites set up by the manufacturers (a general listing of different IC's can be found at www.chipcenter.com). Some manufacturers web sites are listed in table C.1 (this is NOT a recommendation for or against any particular manufacturer, but only a list of some sources of information). You may find the specifications for many types of electronics components on these sites.

Most distributors now have their whole catalogs on-line for easy access. Some distributors that will sell small quantities to individuals and their web sites are listed in table C.2 (again this is NOT a recommendation for or against any particular supplier, but only a list of some that are available):

There are also several companies that produce software for computer aided design of electronic circuits. Some of these companies are listed in table C.3. These programs can be useful for analyzing complicated electronic circuits. Some of these companies offer free downloads of limited-use evaluation

AMD:	www.amd.com
Analog Devices:	www.analog.com
NXP:	www.nxp.com
Intel:	www.intel.com
Renesas (Intersil):	www.renesas.com
On Semiconductor:	www.onsemi.com
Texas Instruments:	www.ti.com

Table C.1: Some Manufacturers

Arrow:	www.arrow.com
Digi-Key:	www.digikey.com
Jameco:	www.jameco.com
JDR:	www.jdr.com
Mouser Electronics:	www.mouser.com
Newark:	www.newark.com

Table C.2: Some Distributors

Circuit Maker:	www.circuitmaker.com
Electronic Workbench:	www.electronicworkbench.com
LTspice	www.linear.com/designtools/software
Spectrum Software:	www.spectrum-soft.com
OrCad	www.orcad.com
Spice	bwrc.eecs.berkeley.edu/Classes/IcBook/SPICE/

Table C.3: Some electronics CAD companies.

or student versions. Again this list is not a recommendation for or against any particular company but just a list of some things that are available.

Bibliography

- [1] J. J. Brophy, *Basic Electronics for Scientists*
- [2] A. J. Diefenderfer, *Principles of Electronic Instrumentation*, 3rd edit. Saunders 1994, ISBN 0-03-074709-0.
- [3] L. R. Fortney, *Princ. of Electronics, Analog and Digital*, (Harcourt, 1987)
- [4] Allan R. Hambley, *Electrical Engineering Principles, Prin. and Applic., 3rd edit.*, Prentice Hall, 2004.
- [5] T. C. Hayes and P. Horowitz, *Student Manual for the Art of Electronics*, Cambridge Univ. Press, 1989, ISBN 0-521-37709-9.
- [6] P. Horowitz and W. Hill, *The Art of Electronics*, 3rd edit., Cambridge Univ Press, 2015, ISBN 978-0521809269.
- [7] J. Millman and A. Grabel, *Microelectronics, 2nd edit.*, McGraw-Hill, 1987, ISBN 0-07-042330-X.
- [8] C. J. Savant, M. S. Roden, G. L. Gordon, *Electronic Design*, 2nd Edit, Benjamin/Cummings, Calif., 1991, ISBN 0-8053-0285-9.
- [9] Paul Scherz and Simon Monk, *Practical Electronics for Inventors, third edit.*, McGraw Hill, 2013.
- [10] A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, third edition, Saunders College Publishing, 1990, ISBN 0-03-051648-X.
- [11] R. E. Simpson, *Intro. Electronics for Scientists and Engineers* 2nd edit., Allyn and Bacon, 1987.
- [12] T. Williams, *The Circuit Designer's Companion* 2nd edit., Newnes, 2010.
- Some books on analog electronics.**
- [13] P. R. Gray, P. J. Hurst, S. H. Lewis and R. G. Meyer, *Analysis and Design of Analog Integrated Circuits*, 4th edit, Wiley, 2001.
- [14] M. N. Horenstein, *Microelectronic Circuits and Devices*, Prentice-Hall 1990.
- [15] Edwin S. Oxner, *Power FETs and Their Applications*, Prentice-Hall, 1982.
- [16] M. E. Van Valkenburg, *Analog Filter Design* (Holt Rinehart and Winston, 1982).

- [17] Darold Wobschall, *Circuit Design for Electronic Instrumentation*, 2nd edit., (McGraw-Hill,1987).

Some books on digital electronics.

- [18] R. Littauer, *Pulse Electronics*

- [19] R. L. Tokheim, *Digital Principles*, third edition, Shaums Outline Series, McGraw Hill 1994, ISBN 0-07-065050-0.

- [20] J. F. Wakerly, *Digital Design, Principles and Practices*, 4th edit., (Prentice Hall 2005) ISBN 0131863894

Some books on computer interfacing.

- [21] D. Abbott, *PCI Bus Demystified*, LLH Technology Publishing, 2000, ISBN 1-878707-54-X

- [22] Jan Axelson, *Parallel Port Complete*, Lakeview Research, 2000, ISBN 0-9650819-1-5

- [23] Jan Axelson, *USB Complete, 3rd edit.*, Lakeview Research, 2005, ISBN13 978-1-931448-02-4

Some books on semiconductor device physics and manufacturing.

- [24] Stephen A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, (Oxford Univ. Press, 1996).

- [25] David J. Elliot, *Integrated Circuit Fabrication Technology* (McGraw-Hill, 1982).

- [26] D. A. Fraser, *The Physics of Semiconductor Devices*, 3rd edit., (Oxford Univ. Press, 1983).

- [27] D. A. Hodges and H. G. Jackson, *Analysis and Design of Digital Integrated Circuits*, (McGraw Hill, 1983) ISBN 0-07-029153-5.

- [28] S. M. Sze, *Semiconductor Devices, Physics and Technology*, (Wiley 1985).

Some books on grounding, and noise reduction and instrumentation.

- [29] Henry W. Ott, *Noise Reduction Techniques in Electronic Systems*, (Wiley, 1976, 2nd edit 1988).

- [30] M. L. Meade, *Lock-in Amplifiers: Principles and Applications*, (Peregrinus, 1983).

- [31] Roland E. Best, *Phase-Locked Loops, Theory, Design, and Applications*, (McGraw-Hill, 1984).

- [32] John H. Moore, Christopher C. Davis and Michael A. Coplan, *Building Scientific Apparatus*, (1st edit. Addison-Wesley, 1983; 3rd edit. Westview Press, 2002)

- [33] Jacob Fraden, *Handbook of Modern Sensors*, (3rd edit. AIP Press, 2004)

- [34] Ralph Morrison, *Instrumentation Fundamentals and Applications, fifth edition*, (Wiley, 2007).

Index

- V_T , 178
- V_T^* , 111, 150
- α , 140
- β , 140
- g_m , 151, 184
- r_b , 151
- r_e , 151
- 20 db/decade, 60
- 555 timer IC, 248
- 74xx00 one-shots, 251

- AC coupling, 123, 161
- active filters, 94
- active low, 198
- active pull-up, 216
- active region, 141, 146
- actuator, 254
- ADC, 291
- addition, 208
- admittance, 53
- AGC, 179
- aliasing, 301
- all-pass filter, 107
- analog signals, 33
- analog transmission gate, 212
- analog-to-digital converter, 291
- AND, 199
- angular frequency, 51
- astable, 250
- astable multivibrator, 46, 133
- asynchronous input, 231
- audible frequencies, 254

- band pass filter, 105
- bandpass filter, 65

- base, 138
- BCD, 241
- beta, 140
- bias, 149, 184
- bias current, 130
- binary, 198
- binary addition, 208
- bit, 260
- bits, 208
- BJT, 137
- BJT circuit model, 143
- Bode Plot, 58, 62
- Bode, Henrik, 58
- Boltzman's constant, 111
- Boolean Algebra, 204
- Boolean algebra, 198, 205
- Boolean identities, 205
- box car integrator, 302
- breadboard, 16
- breakdown, 112, 142
- bypass capacitors, 161
- byte, 260, 269

- CAD, 68
- CAD software, 315
- capacitor, 55
- capacitor charging equation, 19
- capacitors, 14
- cascade, 209
- CCMR, 83
- center tap, 117
- chopper stabalized, 88
- circuit model, 143
- class A amplifier, 165
- class B amplifier, 166

- clipping, 122
- closed loop gain, 80
- CMOS, 201, 214
- CMOS speed, 218
- coaxial cable, 1
- collector, 138
- combinatorial logic, 197, 206, 227
- common emitter amplifier, 160
- common mode rejection ratio, 83
- common mode signal, 82
- common-emitter characteristics, 140
- comparator, 40, 42, 248
- compensation, 75
- compiler, 265
- complex impedance, 53
- complex notation, 52
- complex numbers, 53
- computer IO bus, 261
- computer system, 260
- corner frequencies, 62
- corner frequency, 40, 59
- counters, 239
- CPU, 260
- cross talk, 38
- cross-over distortion, 166
- current control, 87
- current gain, 140
- current source, 29, 143, 159
- current to voltage converter, 87
- curve tracer, 182
- cutoff, 64, 141, 145, 177

- D flip-flop, 231
- DAC, 287
- darlington pair, 162
- data acquisition, 259
- data book, 36
- DC bias, 149
- debounced switch, 229
- decibel, 35
- decoder, 210

- delay circuit, 252
- DeMorgan's Theorem, 207
- demultiplexer, 211
- depletion mode, 175
- depletion region, 110
- differential amplifier, 91, 188
- differential input voltage, 34
- differential pair, 163
- differential signal, 82
- differential signals, 5
- differentiation, 54, 74, 98
- differentiator, 73
- digital sampling scope, 295
- digital signals, 33, 197
- digital-to-analog conversion, 287
- diode characteristics, 132
- diode clipping circuit, 122
- diode drop, 112
- diode edge detector, 126
- diode equation, 111
- diode I-V curve, 114
- diode model, 112
- diode peak detector, 126
- diode pulse stretcher, 125
- diode ratings, 112
- diode voltage drop, 112
- diode wave shaping, 122
- diodes, 109
- distance measurement, 254
- distributors, 315
- duty cycle, 123, 234

- edge detector, 126
- electrons, 110
- emitter, 138
- emitter bias, 157
- emitter coupled pair, 162
- emitter follower, 152
- enhancement mode, 175
- Euler's identity, 52
- exclusive-OR, 200

- fall time, 3
- fanout, 223
- feedback, 79
- filter capacitor, 119
- forward bias, 111
- Fourier analysis, 70
- frequency, 51
- frequency domain, 51, 71, 94, 99
- full adder, 209
- full wave bridge rectifier, 118
- full wave center tap rectifier, 117

- gain margin, 101, 102
- gates, 197
- ground, 1

- h parameters, 140
- half adder, 209
- half-wave rectifier, 117
- Hertz, 51
- high pass filter, 21, 59
- hole, 110
- hybrid parameters, 140
- hysteresis, 44

- I-V curve, 182
- ideal current source, 10
- ideal diode, 109
- ideal op-amp, 43
- ideal voltage source, 9
- impedance, 23, 53
- impedance matching, 24
- inductive load, 148
- inductor, 54
- infinite gain approx., 80
- input bias current, 89, 96, 98
- input offset current, 89
- input offset voltage, 38, 40, 88, 98
- instability, 101
- instrumentation amplifier, 92, 105, 114
- integration, 55, 74, 92, 96
- integrator, 73

- internal compensation, 40
- internal impedance, 23
- internet, 237
- inversion, 198
- inverter, 198
- inverting amplifier, 84
- inverting configuration, 84
- ISA bus, 261, 262

- JK flip-flop, 233
- Johnson noise, 301
- junction, 110

- K, 178
- Karnaugh Maps, 220
- Kirchoff's Laws, 12

- linear amplifier, 149
- linear feedback shift register, 303
- load current, 120
- load line, 143
- log amplifier, 128
- log-log plot, 58
- logic gates, 197
- logic operations, 198
- loop gain, 80
- low pass filter, 18, 61
- LS-TTL, 222

- majority carriers, 137
- manufacturer's data book, 36
- manufacturers, 315
- mask, 293
- MATLAB, 68
- memory, 227
- microphone, 254
- microprocessor, 260
- microprocessor evolution, 263
- minority carriers, 137
- monostable, 249
- Moore's law, 265
- MOSFET, 175
- motherboard, 260

- multiplexer, 210
- n-type region, 110
- NAND, 200
- negation, 198
- negative feedback, 79
- noise, 301, 303
- noise generator, 303
- non-ideal op-amp, 88
- non-inverting amplifier, 84
- non-retriggerable, 252
- NOR, 200
- Norton's Theorem, 29

- offset voltage, 38, 98
- Ohm's Law, 10, 53
- Ohmic region, 178
- one-shot, 249
- op amp, 33
- op-amp integrator, 92
- op-amp summary, 104
- open circuit, 24
- open loop gain, 80
- OpenGL, 295
- operating point, 130
- Operational Amplifier, 33
- operational configuration, 84
- OR, 199
- oscillator, 46, 133, 250
- Oscilloscope, 4
- overdriven op-amp, 40

- p-type region, 110
- parasitic capacitance, 20
- passband, 64
- passive filter, 94
- passive filters, 94
- PCI bus, 261, 262
- peak detector, 126, 133
- peak voltage, 2
- peak-to-peak voltage, 2
- phase, 51
- phase advance, 64
- phase lag, 64
- phase margin, 101
- photodiode, 138
- pickoff, 125
- pickup, 1
- piezoelectric crystal, 254
- pinch off, 178
- pn junction, 110
- polar form, 54
- pole-zero form, 62
- poles, 62
- positive feedback, 43, 44
- power, 165
- power MOSFET, 191
- power supplies, 37
- precision diode, 128
- primary winding, 116
- probes, 8
- programming, 265
- Propagation Delay, 230
- propagation delay, 43
- pulse stretcher, 125
- pulse stretching, 125
- push-pull amplifier, 166
- python, 69

- Q-point, 130, 149
- quartz, 254
- quiescent point, 130

- R-2R ladder, 287
- R-S flip-flop, 227
- rail voltage, 33
- RAM, 212, 261
- rangefinder, 254
- RC timing, 247
- reactance, 54, 55
- read only memory, 212
- read-write memory, 212
- real time control, 259
- rectangular form, 54

- rectification, 116
- rectifier, precision, 128
- registers, 236
- resistor color code, 11
- resistors, 10
- resonance frequency, 57
- retriggerable, 252
- reverse bias, 110
- reverse saturation current, 111
- ring oscillator, 230
- ripple counter, 239
- rise time, 3, 7, 20
- rms voltage, 2
- rolloff, 40, 101
- ROM, 212, 261

- sampling, 295
- saturated switch, 248
- saturating inverter, 144
- saturation, 141
- saturation current, 111
- saturation region, 141, 146, 178, 179
- Schmitt trigger, 43, 219
- scope, 4
- scope probe, 75
- scope probes, 8
- secondary winding, 116
- sensor, 254
- sequential logic, 206, 227
- serial data, 237
- shielding, 1
- shift register, 237
- short circuit, 24
- signal averager, 301
- silicon diode, 109
- sink, 217
- sinusoidal signals, 51
- sinusoidal steady state, 51
- slew rate, 43
- small signal amplification, 38
- solderless breadboard, 16

- source, 217
- source impedance, 23, 27
- speaker, 254
- spec sheet, 36
- spectrum, 70
- spreading resistance, 131
- stability, 101, 102
- static discharge, 176
- successive approximation ADC, 293
- summing amplifier, 90
- summing junction, 90
- Superposition, 13
- supply rails, 33
- supply voltage, 33
- switch debouncer, 229
- synchronous counter, 239
- synchronous input, 231
- synchronous system, 235

- TDS-1002, 4
- TDS-210, 4
- Tektronix, 4
- temperature, 111
- thermal noise, 301
- thermal runaway, 113
- Thevenin's Theorem, 25
- threshold voltage, 178
- time constant, 18, 21
- time domain, 51, 71
- toggle, 233
- totem-pole, 214
- transconductance, 150, 184
- transducer, 1, 260
- transducers, 247, 254
- transfer characteristic, 35
- transfer function, 58, 62
- transformer, 116
- transimpedance, 87
- transistor active region, 141
- transistor breakdown, 142
- transistor circuit model, 143

transistor cutoff, 141
transistor saturation, 141
transistors, 137, 175
transmission gate, 212
tri-state, 278
tri-state output, 220
Triode region, 178
truth table, 198
TTL, 222
TTL logic levels, 203
TTL speed, 224

ultrasonic transducer, 254
USB bus, 262

virtual ground, 85, 87
voltage, 1
voltage amplification, 35
voltage comparator, 42
voltage divider, 11, 25
voltage doubler, 119
voltage follower, 83, 102
voltage reference, 113, 134
voltage regulator, 121

wave shaping, 122, 126

XOR, 200

zener diode, 113
zero crossing distortion, 166
zeros, 62

UG-01080 2020.06.02 To HSSI Pins. Native Transceiver PHYs. Each device family, beginning with Series V devices offers a separate Native PHY IP core to provide low-level access to the hardware. Introduction to the Protocol-Specific and Native Transceiver PHYs Send Feedback. UG-01080 2020.06.02. Figure 1-2: Stratix V Transceiver Native PHY IP Core. Native Transceiver PHYs. ATTENTION Please read this instruction manual carefully before installing and operating the instrument. Not following the guidelines could result in personal injury and/or damage to the equipment. BRONKHORST®. Disclaimer. The information in this manual has been reviewed and is believed to be wholly reliable. No responsibility, however, is assumed for inaccuracies. The material in this manual is for information purposes only. Hook-up diagram laboratory-style MBC RS232 + analog Hook-up diagram industrial style MBC-II RS232 + analog Hook-up diagram CORI-FLOW RS232 + analog Hook-up diagram LIQUI-FLOW L30 digital RS232 + analog. (document nr. 9.16.062) (document nr. 2College of Physics and Electronic Engineering, Hengyang Normal University, Hengyang 421002, China 3Department of Physics, Key Laboratory for Low-Dimensional Structures and Quantum Manipulation (Ministry of Education), and Synergetic Innovation Center for Quantum Eects and Applications of Hunan, Hunan Normal University, Changsha 410081, China. [3] F. Xia, H. Wang, J. C. M. Hwang, A. H. Castro, and L. Yang, Black phosphorus and its isoelectronic materials, Nat. Rev. Phys. 1, 306 (2019). [4] A. Molle, J. Goldberger, M. Houssa, Y. Xu, S.-C. Zhang, and D. Akinwande, Buckled two-dimensional Xene sheets, Nat. Mater. DEA laboratories provide advisory, scientific and technical services to DEA, federal law enforcement, intelligence operations, and the criminal justice system at large. Each laboratory serves geographic area defined by SF (Exhibit 1/7001). Policy statements within the Laboratory Operations Manual (LOM) are mandatory requirements. The word "should" within a statement signifies a best-practice, or recommendation. The word "may" in a statement provides permission that does not require additional authorization. The : future : laboratory. : : nespresso professional : w orkplace futures. : Part One: Foresight Overview : 2 : Part Two: The Fluid Workforce : 4 : New Bricolage Living : The Optimised Self : Post-growth Society : The Focus Filter Part Three: Workplace Futures : 10 Workplace 2030: The Communal Workplace : Hospitality Ethos : Multimodal Design : Resilience Culture : Civic Purpose Part Four: Conclusion : 24.