



# INDEX

## 2

20-H rule ..... 173

## A

AC (Alternating Current) .... 8, 10, 12, 49, 74, 157, 164, 305, 340, 378, 387  
 Admittance ..... 142, 387  
 Aggressor ... 221, 223, 238, 242, 387, 391  
 Ampere, Andre ..... 5, 26, 155, 329  
 Amplifier gain ..... 85  
 Antenna ..... 36, 91, 92, 156, 168, 180  
 Anti-resonance ..... 292, 387  
 Arctangent ..... 124  
 Atom ..... 3, 387  
 Atomic number ..... 3  
 Atomic weight ..... 3

## B

Bandwidth ..... 21, 137, 387  
 Broadside coupled ..... 268

## C

Capacitive coupling ..... 222, 257  
 Capacitive loading ..... 188, 206  
 Capacitive reactance ..... 98  
 Capacitor, capacitance ..... 388  
     bypass ..... 273

calculating ..... 48, 282  
 hydrauloc analog ..... 43  
 impedance ..... 278  
 parallel ..... 45  
 phase shift ..... *See* Phase angle, shift  
 planar ..... 275, 282, 295, 300  
 RC time constant ..... 74, 132  
 series ..... 45  
 time constant ..... 194  
 voltage and current through ..... 64  
 Characteristic impedance .....  
     *See* Impedance, transmission  
         line  
 capacitive loading ..... 206  
 Charge ..... 27, 40, 155, 296, 329, 388  
     AC termination ..... 194  
     bypass capacitor ..... 273  
     capacitor ..... 43, 47, 57, 64  
     conservation of ..... 78  
     coulomb ..... 5  
     crosstalk ..... 221  
     direction of flow ..... 23  
     farad ..... 47  
     relative dielectric coefficient ..... 28  
 Common mode ..... 169, 249, 255, 388  
 Communications model ..... 175  
 Complex number ..... 388  
 Conductance ..... 94  
 Coulomb ..... 5, 64, 389  
 Coulomb, Charles ..... 1, 5, 26, 329  
 Coulomb's Law ..... 1, 6, 329  
 Coupling

- 
- crosstalk ..... 221  
 differential ..... 257, 261  
 EMI ..... 159  
 power system ..... 304  
 to return signal ..... 343  
 Critical length ..... 183, 389  
 Crosstalk ..... 300, 340, 389  
     backward ..... 223, 387  
     estimating ..... 226  
     forward ..... 225, 391  
     simulation ..... 235, 239, 242, 244  
 Current ..... 3, 4, 26, 56, 221, 389  
     and Ohm's Law ..... 39  
     and reactance ..... 97  
     changing ..... 155, 156, 159, 222, 312,  
         314, 334, 338, 340  
     changing through inductor ..... 54  
     charge/discharge ..... 56  
     charge/discharge in AC termination  
         ..... 194  
     charging a capacitor ..... 64  
     constant within loop ..... 152, 251  
     coupling ..... 159  
     coupling to adjacent trace ..... 343  
     coupling to plane ..... 257  
     crosstalk coupling ..... 221  
     definition ..... 5, 25  
     density ..... 302, 313  
     density under trace ..... 228, 298  
     direction of flow ..... 23  
     EMI coupling ..... 156  
     flow of electrons ... 1, 3, 6, 23, 38, 64,  
         78, 152, 155, 158, 221, 273,  
         299, 332, 389  
     flows in closed loop ..... 152, 158, 251,  
         257, 271  
     ground loop ..... 303  
     ideal source ..... 121  
     loop ..... 161, 165, 193, 300  
     loop area in differential pair ..... 256  
     return .. 157, 159, 160, 165, 193, 197,  
         251, 300, 305  
     return from trace layers ..... 198  
     return from unmatched pairs ..... 253  
     return on plane ..... 343  
     skin effect ..... 312  
     transformer ..... 338
- D**
- DC (Direct Current) ..... 8, 12, 13, 49, 54,  
     160, 164, 192, 212, 222, 277, 303,  
     389  
 di/dt ..... 66, 67, 271, 335, 389  
 Dielectric absorption ..... 314, 389  
 Differential impedance ..... 260, 389  
     broadside coupled ..... 268  
     calculating ..... 266  
     edge coupled ..... 266  
     simulation ..... 262  
 Differential mode ..... 169, 170, 249, 390  
 Differential traces ..... 390  
     advantages ..... 249  
     design rules ..... 255  
     EMI ..... 252, 257  
     timing ..... 32  
 Downware sloping curve ..... 280  
 dV/dt ..... 64, 298
- E**
- e ..... 73, 346, 390  
 Edge coupled ..... 266  
 Electromagnet ..... 155  
 Electromagnetic coupling ..... 159, 221, 343,  
     390  
 Electromagnetic field ..... 27, 155  
 Electromagnetic interference ..... *See* EMI  
 Electron ..... 3, 27, 43, 155, 221, 269, 273,  
     387, 388, 390  
     flow ..... *See* Current  
     shell ..... 3  
 EMI ..... 156, 202, 255, 390  
     20-H rule ..... 173  
     changing trace layer ..... 165, 199  
     common mode ..... 169  
     differential pair loop ..... 257  
     differential trace length ..... 252, 253  
     Faraday shield ..... 174  
     impedance peaks ..... 284  
     loop area ..... 161, 167  
     pad clearance ..... 164

picket fence ..... 174  
plane pairs ..... 300  
reference plane ..... 300  
return path ..... 163  
right-angle corner ..... 384  
slots in planes ..... 162  
stripline environment ..... 168  
stubs ..... 168  
Thevenin termination ..... 193  
twisted pair ..... 157  
unrelated plane ..... 167  
Equalization ..... 390  
  active ..... 319  
  passive ..... 319  
Equivalent circuit ..... 79, 89, 215, 390  
  Norton ..... 89  
  Thevenin ..... 89, 211, 375  
ESR (equivalent series resistance) ..... 107,  
  137, 285, 296, 358, 373, 390  
  and anti-resonance ..... 292  
  and anti-resonant peak ..... 286  
  and self-resonance ..... 292  
  and system resonance ..... 291  
Even mode ..... 249, 256,  
  *See also* Common mode  
Eye diagram ..... 316, 391

## F

Fall time ..... *See* Rise time  
Farad ..... 25, 47, 391  
Faraday shield ..... 174  
Faraday, Michael ..... 26, 47, 156, 329  
Faraday's Law ..... 156, 329  
Fourier ..... 18, 391  
  impulse signal ..... 22  
  sawtooth wave ..... 22  
  triangular wave ..... 22  
Frequency ..... 76, 97, 121, 128  
  angular ..... 18, 98, 391  
  anti-resonant ..... 291, 387  
  cutoff ..... 132  
  cyclical (Hertz) ..... 16  
  definition ..... 13, 391  
  harmonic ..... 11, 19, 152, 312, 392  
  measurement ..... 16

resonant ..... 113, 287, 395  
self-resonant ..... 280, 288, 291, 295

## G

Gauss, Carl Friedrich ..... 26, 329, 363  
Generator ..... 337, 391  
Ground bounce ..... 272  
Guard band ..... 233, 391

## H

Harmonic ..... 11, 19, 129, 152, 165, 284, 312,  
  325, 392  
  distortion ..... 149  
Henry ..... 25, 54, 392  
Henry, Joseph ..... 26

## I

$i^2R$  ..... 87, 91  
Impedance ..... 122, 289, 300, 383, 392,  
  *See also* Transmission line  
  calculation ..... 203, 266  
  characteristic ..... 179  
  common mode ..... 261  
  differential ..... 261  
  parallel ..... 134  
  series ..... 133  
  transmission line ..... 188, 315  
Inductive coupling ..... 222, 257  
Inductor, inductance ..... 25, 312, 392  
  and rise time ..... 150  
  calculating ..... 55  
  ground bounce ..... 270  
  ground plane ..... 170  
  hydraulic analog ..... 50  
  ignition coil ..... 70  
L/R time constant ..... 75  
lead ..... 278, 373  
methods for increasing ..... 341  
mutual inductance ..... 340  
parallel ..... 53, 103  
phase shift ..... *See* Phase angle, shift  
reactance ..... 99  
RL circuit ..... 58

self inductance.....313, 340  
 series.....52, 103  
 voltage and current through.....66  
 voltage spike.....70

**J**

*j*, imaginary. 123, 146, 290, 361, 392, 393

**K**

Kirchhoff.....77, 169  
 1<sup>st</sup> Law.....78, 109  
 2<sup>nd</sup> Law.....40, 78, 112  
 Kirchhoff, Gustav.....26

**L**

L/R time constant .....*See* Time constant  
 LC circuit.....104, 107, 115  
 resonance.....280, 283  
 transmission line.....178, 311  
 Loop area.....161, 300, 393  
 differential trace .....257  
 differential traces.....257  
 EMI .....*See* EMI

**M**

Maxwell, James Clerk .....1, 26, 330  
 Maxwell's equations.....330  
 Microstrip .....393  
 configuration .....29  
 crosstalk.....226  
 differential impedance.....266  
 impedance formula.....203  
 propagation speed.....30  
 tuning.....33  
 Motor .....333, 393

**N**

Norton equivalent circuit .....89  
 Norton, E.L.....26

**O**

Odd mode .....249, 256, 260,  
*See also* Differential mode  
 Ohm .....393  
 definition .....25  
 meter.....334  
 zero-ohm resistor.....303  
 Ohm, George Simon .....26  
 Ohm's Law ..3, 57, 77, 86, 130, 136, 160,  
 258, 298, 393  
 definition .....39  
 for admittance .....142  
 for reactance .....101  
 Overlapping planes .....304

**P**

Period .....14, 393  
 Periodic Table.....4  
 Phase angle, shift .....9, 59, 99, 351, 394  
 admittance .....143  
 and Fourier's Theorem .....18  
 definition .....124  
 differential traces .....252  
 impedance .....123  
 impedance curve .....280  
 parallel bypass capacitors .....290  
 phase shift simulator .....351  
 reactance .....97  
 resonance .....290  
 RLC simulation .....145  
 Square Wave Simulator .....327  
 variable network analyzer .....378  
 Picket fence .....174  
 Pole and zero .....118, 291  
 Power .....25, 86, 91  
 Power curve .....92  
 Propagation speed .....28, 30, 394  
 and wavelength .....35  
 electromagnetic field .....155  
 microstrip .....30  
 Propagation time .....28, 394  
 and critical length .....181  
 capacitive loading .....188, 206  
 microstrip .....31  
 Proton .....3

**Q**

Q ..... 136

**R**

Radian ..... 16, 394

RC circuit

charging and discharging ..... 57, 72

equalization ..... 319

phase relationship ..... 121

RC filter ..... 131

RC time constant ..... *See* Time constant

Reactance ..... 283, 394

at resonance ..... 111

capacitive ..... 98

definition ..... 97

inductive ..... 98, 99

Ohm's Law for ..... 101

parallel combination ..... 102

phase shift ..... 98

relationship to impedance ..... 122

series combination ..... 102

Reference plane ..... 230, 267, 300, 308, 396

control common mode ..... 172

control of crosstalk ..... 227

control of EMI ..... 161, 170

control of impedance ..... 197

microstrip ..... 393

signal return ..... 153

signal transition ..... 165

stripline ..... 395

trace configuration ..... 29

Reflect, reflection ..... 150, 176, 379,

*See also* Transmission line

and differential traces ..... 260

backward crosstalk ..... 224

critical length ..... 181

crosstalk termination ..... 229

design issues ..... 196

echo illustration ..... 369

on transmission line ..... 180

simulation ..... *See* Transmission line

simulation

simulation. *See* Crosstalk, simulation

stubs ..... 200

TDR ..... 376

termination ..... 180

VNA ..... 376

Reflection coefficient ..... 183, 211

Relative dielectric coefficient ..... 28, 190, 389, 394

Resistor, resistance ..... 25, 77, 395,

*See also* ESR

hydraulic analog ..... 38

parallel ..... 41, 81

series ..... 40, 79

terminating ..... *See* Transmission lineterminating ..... *See* Termination voltage and current through ..... 63

Resonance ..... 61, 111, 290, 395

LC circuit ..... 113

phase shift ..... 115

Q ..... 134

RLC circuit ..... 140

Resonant, self ..... 280

Reverse voltage diode ..... 70

Right angle corner ..... 383

Right hand rule ..... 156, 330, 395

Rise time ..... 68, 147, 150, 183, 226, 228,

    256, 395, *See also*  $\frac{di}{dt}$ 

and bandwidth ..... 21

and crosstalk ..... 222

and frequency ..... 14, 21

and ground bounce ..... 271

and lower voltages ..... 298

and signal coupling ..... 160

critical length ..... 181

definition ..... 14

fall time ..... 16

harmonics ..... 129

reflection ..... 177, 369

stub length ..... 201

RL circuit ..... 58, 74

RLC circuit ..... 134, 137, 351

resonance ..... 140

simulation ..... 145

RMS (root mean square) ..... 12, 395

**S**

Signal

- 
- return ..... 153, 157, 159, 298, 343  
 return and plane boundary ..... 305  
 return and slots ..... 232  
 return on different layers ..... 165  
 return on power plane ..... 164  
 return path ..... 163  
 return plane discontinuity ..... 167  
 trace geometry ..... 197  
 Signal coupling ..... *See* Coupling  
 Signal timing, tuning ..... 32, 33  
 Sine wave ..... 8, 11  
     and Fourier's Theorem ..... 18  
 Single ended ..... 249  
 Skin effect ..... 312, 395  
 Slot ..... 162, 199, 232  
 Spark plug ..... 70  
 Square wave ..... 14, 19, 252  
 Square wave simulation ..... 325  
 Stackup ..... 307  
 Stripline ..... 242  
 Stub ..... 168, 200, 395  
 Susceptance ..... 119, 395  
 Symbols ..... 24
- T**
- TDR (time domain reflectometer) ..... 375, 396  
 Termination ..... 229, 242, 396  
 Thevenin ..... 89, 192, 211  
 Time constant ..... 57, 74, 396  
     L/R ..... 75  
     RC ..... 74, 132, 194  
 Trace configurations ..... 29, 265  
 Trace layer ..... 165, 196  
 Transformer ..... 338  
 Transmission line ..... 178, 396  
     impedance ..... 201  
     lossy ..... 311  
     simulation ..... 184, 367  
     termination ..... *See* Transmission line termination  
 Transmission line simulation
- basic ..... 207  
 branch ..... 219  
 placement of termination ..... 217  
 series termination ..... 215  
 Transmission line termination ..... 179, 190  
     AC ..... 194  
     differential traces ..... 258, 260  
     diode ..... 195  
     parallel ..... 192  
     series ..... 194  
     Thevenin ..... 192  
 Tuned trace ..... 396
- U**
- Upward sloping curve ..... 280
- V**
- VNA (vector network analyzer) ..... 375, 396  
 Volt ..... 25, 47, 54, 64  
 Volta, Allesandro ..... 26  
 Voltage ..... 6, 8, 37, 63, 396  
     gradient ..... 299  
     ideal source ..... 37, 67, 77, 129, 351, 389  
     meter ..... 13, 334  
     noise ..... 150, 202  
     phase ..... *See* Phase angle, shift  
     reference ..... 276  
     reflection ..... *See* Reflect, reflection  
     reverse ..... *See* Reverse voltage diode  
     source ..... 89  
     spike ..... 70  
 Voltage divider ..... 84, 131, 170, 211, 215, 238
- W**
- $\omega$  (angular frequency) ..... *See* Frequency, angular  
 Wavelength ..... 35, 174, 396