

Contents

Preface	xvii
Abbreviations	xxi
1 Introduction to Spectrum and Network Measurements	1
1.1 Signals and Systems	1
1.2 Time Domain and Frequency Domain Relationships	2
1.3 System Transfer Function	3
1.4 Advantages of using Frequency Domain Measurements	4
1.5 Spectrum Measurements	5
1.6 Network Measurements	7
1.7 Combined Spectrum/Network Analyzers	9
1.8 Modular Instruments	10
Bibliography	10
2 Decibels	11
2.1 Definition of the Decibel	11
2.2 Cardinal Values	13
2.3 Absolute Decibel Values	14
2.4 Gain and Loss Calculations	17
2.5 Decibels and Percent	19
2.6 Error Expressed in Decibels	20
Bibliography	21
3 Fourier Theory	23
3.1 Periodicity	23
3.2 Fourier Series	24
	vii

3.3	Fourier Series of a Square Wave	25
3.4	Fourier Series of Other Waveforms	30
3.5	Fourier Transform	31
3.6	Fourier Transform of a Pulse	32
3.7	Inverse Fourier Transform	33
3.8	Fourier Transform Relationships	33
3.9	Discrete Fourier Transform	36
3.10	Limitations of the DFT	38
3.11	Fast Fourier Transform	39
3.12	Relating Theory to Measurements	39
3.13	Finite Measurement Time	40
	Bibliography	41
4	Fast Fourier Transform Analyzers	43
4.1	The Bank-of-Filters Analyzer	43
4.2	Frequency Resolution	44
4.3	The FFT Analyzer	45
4.4	Sampled Waveform	46
4.5	Sampling Theorem	47
4.6	FFT Properties	51
4.7	Controlling the Frequency Span	52
4.8	Band Selectable Analysis	53
4.9	Leakage	55
4.10	Hanning Window	55
4.11	Flattop Window	58
4.12	Uniform Window	59
4.13	Exponential Window	60
4.14	Selecting a Window Function	62
4.15	Oscillator Characterization	62
4.16	Spectral Maps	63
4.17	Time Domain Display	65
4.18	Network Measurements	65
4.19	Phase	66

4.20	Electronic Filter Characterization	67
4.21	Cross-Power Spectrum	68
4.22	Coherence	70
4.23	Correlation	72
4.24	Autocorrelation	73
4.25	Cross-Correlation	75
4.26	Histogram	76
4.27	Real-Time Bandwidth	78
4.28	Real-Time Bandwidth and RMS Averaging	79
4.29	Real-Time Bandwidth and Transients	80
4.30	Overlap Processing	81
4.31	Swept Sine	83
4.32	Octave Measurements	84
	Bibliography	85
5	Swept Spectrum Analyzers	87
5.1	The Wave Analyzer	87
5.2	Heterodyne Block Diagram	88
5.3	The Swept Spectrum Analyzer	89
5.4	Practical Considerations	91
5.5	Input Section	91
5.6	Resolution Bandwidth	92
5.7	Sweep Limitations	92
5.8	Specialized Sweep Modes	95
5.9	Local Oscillator Feedthrough	95
5.10	Digital IF Section	96
5.11	Types of Detectors	97
5.12	The Tracking Generator	98
5.13	FFT versus Swept Measurements	98
5.14	Modern Spectrum Analyzer Block Diagrams	99
5.15	Real-Time Spectrum Analyzer	101
5.16	Types of Spectrum Analyzers	103
	Bibliography	104

6	Modulation Measurements	107
6.1	The Carrier	107
6.2	Amplitude Modulation	108
6.3	AM Measurements	113
6.4	Zero-Span Operation	114
6.5	Other Forms of Amplitude Modulation	115
6.6	Angle Modulation	115
6.7	Narrowband Angle Modulation	118
6.8	Wideband Angle Modulation	119
6.9	FM Measurements	122
6.10	Combined AM and FM	123
6.11	Digital Modulation	125
6.12	Quadrature Modulation	126
6.13	Common Digital Modulation Formats	127
6.14	Error Vector Magnitude	131
6.15	Channel Measurements	133
	Bibliography	135
7	Distortion Measurements	137
7.1	The Distortion Model	137
7.2	Single-Tone Input	138
7.3	Two-Tone Input	139
7.4	Higher-Order Models	142
7.5	The Intercept Concept	142
7.6	Harmonic Distortion Measurements	145
7.7	Use of Low-Pass Filter on Source	146
7.8	Intermodulation Distortion Measurements	147
7.9	Distortion Internal to the Analyzer	148
	Bibliography	149
8	Noise and Noise Measurements	151
8.1	Statistical Nature of Random Noise	151
8.2	Mean, Variance, and Standard Deviation	152

8.3	Power Spectral Density	153
8.4	Frequency Distribution of Noise	153
8.5	Equivalent Noise Bandwidth	155
8.6	Noise Units and Decibel Relationships	157
8.7	Noise Measurement	158
8.8	Automatic Noise Level Measurement	159
8.9	Noise Floor	159
8.10	Correction for Noise Floor	160
8.11	Phase Noise	161
	Bibliography	165
9	Pulse Measurements	167
9.1	Spectrum of a Pulsed Waveform	167
9.2	Effective Pulse Width	169
9.3	Line Spectrum	170
9.4	Pulse Spectrum	171
9.5	Pulsed RF	174
9.6	Pulse Desensitization	175
	Bibliography	176
10	Averaging and Filtering	177
10.1	Predetection Filtering	177
10.2	Predetection Filters	179
10.3	Postdetection Filtering	180
10.4	Postdetection Filters	181
10.5	Averaging	183
10.6	Variance Ratio	183
10.7	General Averaging	184
10.8	Linear Weighting	185
10.9	Exponential Weighting	185
10.10	Averaging in Spectrum and Network Analyzers	187
10.11	RMS Average	188

10.12	Vector Averaging	188
10.13	Smoothing	191
10.14	Averaging versus Filtering	191
	Bibliography	193
11	Transmission Lines	195
11.1	The Need for Transmission Lines	195
11.2	Distributed Model	196
11.3	Characteristic Impedance	196
11.4	Propagation Velocity	197
11.5	Generator, Line, and Load	197
11.6	Impedance Changes	201
11.7	Sinusoidal Voltages	202
11.8	Complex Reflection Coefficient	203
11.9	Return Loss	203
11.10	Standing Waves	204
11.11	Input Impedance of a Transmission Line	207
11.12	Measurement Error Due to Impedance Mismatch	209
11.13	Insertion Gain and Loss	212
11.14	Line Losses	216
11.15	Coaxial Lines	216
	Bibliography	217
12	Measurement Connections	219
12.1	The Loading Effect	219
12.2	Maximum Voltage and Power Transfer	220
12.3	High-Impedance Inputs	220
12.4	Active High-Impedance Probes	223
12.5	Z_0 Impedance Inputs	223
12.6	Input Connectors	224
12.7	Z_0 Terminations	225
12.8	Power Dividers and Splitters	225
12.9	Attenuators	228

12.10 Return Loss Improvement	230
12.11 The Classical Attenuator Problem	232
12.12 Impedance Matching Devices	234
12.13 Measurement Filters	236
Bibliography	238
13 Two-Port Networks	241
13.1 Sinusoidal Signals	241
13.2 The Transfer Function	243
13.3 Improved Two-Port Model	244
13.4 Impedance Parameters	245
13.5 Admittance Parameters	246
13.6 Hybrid Parameters	246
13.7 Transmission Parameters	247
13.8 Scattering Parameters	247
13.9 Transfer Function and S_{21}	250
13.10 Why S-Parameters?	250
Bibliography	251
14 Network Analyzers	253
14.1 Basic Network Measurements	253
14.2 Oscilloscope and Sweep Generator	253
14.3 Network Measurements Using a Spectrum Analyzer	254
14.4 Vector Network Analyzer	255
14.5 Directional Bridges and Couplers	257
14.6 S-Parameter Test Set	257
14.7 Modern Vector Network Analyzer Configurations	259
14.8 Sweep Limitations	260
14.9 Power Sweep	262
14.10 Flexible Source Frequency	262
14.11 VNA Time Domain Measurements	264
14.12 Nonlinear VNA Measurements	265
Bibliography	265

15	Vector Network Measurements	267
15.1	Distortionless Transmission	267
15.2	Nonlinearity	269
15.3	Linear Distortion	269
15.4	Importance of Linear Phase	270
15.5	Group Delay	273
15.6	Normalization	275
15.7	Measurement Plane	278
15.8	Reflection Measurements	279
15.9	Directional Bridges and Couplers	284
15.10	Reflection Configuration	287
15.11	Reflection Normalization	288
15.12	Error in Reflection Measurements	289
15.13	Vector Error Correction	290
15.14	Normalization Revisited	291
15.15	Two-Term Error Correction	291
15.16	Three-Term Error Correction	291
15.17	Two-Port Error Correction	293
	Bibliography	295
16	EMC Measurements	297
16.1	Electromagnetic Compatibility	297
16.2	Radiated Emissions	298
16.3	Antennas	300
16.4	Near Field and Far Field	303
16.5	EMI Receiver Requirements	304
16.6	Peak, Quasi-Peak, and Average Detectors	305
16.7	Conducted Emissions	306
16.8	Line Impedance Stabilization Network	306
16.9	EMC Troubleshooting	309
16.10	Near-Field Probes	310
16.11	Current Probe	312
16.12	Preamplifiers	313
	Bibliography	314

17 Analyzer Performance and Specifications	315
17.1 Source Specifications	315
17.2 Receiver Characteristics	317
17.3 Spectrum Analyzer Dynamic Range	319
17.4 Network Analyzer Specifications	321
Bibliography	324
Appendix A	325
Index	329