

Contents

- 1 Fundamentals 1**
 - 1.1 Introduction 1
 - 1.2 RF Power Amplifier Characteristics 2
 - 1.3 Figures of Merit 4
 - 1.3.1 Drain Efficiency and Power Added Efficiency 5
 - 1.3.2 Intermodulation and Harmonic Distortions 6
 - 1.3.3 Adjacent Channel Power Ratio 8
 - 1.3.4 Error Vector Magnitude 9
 - 1.4 Power Amplifier 10
 - 1.5 Power Amplifier Design Methodologies 14
 - 1.5.1 CAD-Based Design Methods 14
 - 1.5.2 Measurement-Based Design Methods 15
 - 1.6 Nonlinear Microwave Measurement System 16
 - 1.6.1 What Is Load-Pull? 17
 - 1.6.2 Why Load-Pull? 17
 - 1.7 Important Load-Pull Features 18
 - 1.7.1 Repeatability of Reflection Coefficients 19
 - 1.7.2 Tuning Range and Its Distribution 19
 - 1.7.3 Tuning Speed 20
 - 1.7.4 Power Handling Capability 20
 - 1.7.5 Tuner Resolution 20
 - 1.7.6 Tuner Bandwidth 21
 - 1.7.7 Tuner Size 21
 - 1.8 Common Load-Pull Systems 22
 - References 23
- 2 Passive Load-Pull Systems 29**
 - 2.1 Introduction 29
 - 2.2 Passive Load-Pull System 30
 - 2.2.1 Electromechanical Tuner (EMT) 30
 - 2.2.2 Electronic Tuner (ETS) 33

2.2.3	ETS and EMT Comparisons	34
2.3	Load-Pull Measurement	35
2.3.1	Load-Pull Setup	36
2.3.2	System Calibration	38
2.4	Harmonic Load-Pull System	42
2.4.1	Triplexer Based Harmonic Load-Pull Setup	44
2.4.2	Harmonic Rejection Tuner Based Harmonic Load-Pull Setup	45
2.4.3	Single Tuner Harmonic Load-Pull Setup	46
2.4.4	Harmonic Load-Pull Comparisons	47
2.5	Tuning Range Enhancement	49
2.5.1	Enhanced Loop Architecture	50
2.5.2	Cascaded Tuner	51
	References	52
3	Active Load-Pull Systems	55
3.1	Introduction	55
3.2	Closed-Loop Load-Pull System	56
3.2.1	System Realization	56
3.2.2	Analysis of Closed-Loop System	57
3.3	Closed-Loop Load-Pull Architectures	62
3.4	Optimized Closed-Loop Load-Pull System	64
3.5	Feed-Forward Load-Pull System	68
3.6	Optimized Feed-Forward Load-Pull System	71
3.7	Harmonic Feed-Forward Load-Pull System	74
3.8	Open-Loop Load-Pull System	76
3.9	Convergence Algorithm for Open-Loop and Feed-Forward Load-Pull Techniques	78
3.10	Comparison of Active Load-Pull Techniques	83
	References	84
4	Six-Port Based Load-Pull System	87
4.1	Introduction	87
4.2	Impedance and Power Flow Measurement	88
4.3	SP in Reverse Configuration	89
4.3.1	SP Calibration in Reverse Configuration	89
4.3.2	Error Box Calculation	93
4.3.3	Discussion	94
4.4	SP Based Source-Pull Configuration	95
4.5	SP Based Load-Pull Configuration	96
4.5.1	Passive Load-Pull System	96
4.5.2	Active Branch Load-Pull System	97
4.5.3	Active Loop Load-Pull System	99
4.6	On-Wafer Load-Pull Measurements	99
4.7	Applications of Source-Pull Setup	101
4.7.1	Low Noise Amplifier Characterization	102
4.7.2	Mixer Characterization	103

4.7.3	Power Amplifier Characterization	104
4.8	Oscillator Measurements	104
4.9	AM/AM and AM/PM Measurements	106
4.9.1	Principles of Operation	107
4.9.2	Measurement Procedure	110
	References	110
5	High-Power Load-Pull Systems	113
5.1	Introduction	113
5.2	Limitations of Existing Load-Pull Systems	113
5.2.1	Problems Due to High Standing Waves	114
5.2.2	Problem of Large Load-Pull Power	118
5.3	High-Power Load-Pull	119
5.3.1	Pre-matching Technique	120
5.3.2	Enhanced Loop Architecture	122
5.3.3	Quarter Wave Transformer Technique	124
5.3.4	Broadband Impedance Transformer Technique	126
5.4	Impact of a Transformation Network on P_{LP} and VSWR	127
5.5	Hybrid Load-Pull System	130
5.6	Calibration and Data Extraction	133
	References	136
6	Envelope Load-Pull System	139
6.1	Introduction	139
6.2	Envelope Load-Pull Concept	140
6.2.1	Mathematical Formulation	140
6.3	Practical Realization	142
6.3.1	Design of Control Unit	142
6.4	ELP Calibration	145
6.4.1	Error Flow Model Formulation	145
6.4.2	Simplification of the Error Flow Model	146
6.4.3	Calibration Technique	148
6.4.4	Evaluation of the Calibration Technique	150
6.5	Stability Analysis	153
6.6	Features of the Envelope Load-Pull System	154
6.7	Harmonic Envelope Load-Pull System	155
6.8	Unique Measurement Applications	157
	References	160
7	Waveform Measurement and Engineering	163
7.1	Introduction	163
7.2	Theoretical Formulation	164
7.3	Historical Perspectives	165
7.4	Practical Waveform Measurement System	169
7.5	System Calibration	170
7.5.1	First Step: Power Flow Calibration	171

7.5.2	Second Step: S-Parameter Calibration	172
7.5.3	Third Step: Enhanced Calibration	174
7.5.4	Calibration Evaluation	175
7.6	Six-Port Based Waveform Measurement System	177
7.6.1	Multi-harmonic Reference Generator	178
7.6.2	SP Reflectometer Principle	178
7.6.3	Multi-harmonic SP Reflectometer Architecture	179
7.6.4	Multi-harmonic SP Reflectometer Calibration	181
7.6.5	Calibration Verification	182
7.7	Waveform Engineering	183
7.8	Applications of Waveform Engineering	184
7.8.1	Transistor Characterization	184
7.8.2	CAD Incorporation	185
7.8.3	Power Amplifier Design	186
	References	187
8	Advanced Configurations and Applications	191
8.1	Introduction	191
8.2	Multi-tone Load-Pull Technique	191
8.3	Real-Time Multi-harmonic Load-Pull Technique	197
8.4	Modulated Signal Load-Pull Technique	201
8.5	Multi-tone Envelope Load-Pull Technique	204
8.6	Wideband Load-Pull Technique	208
8.6.1	Wideband Load-Pull Approach	209
8.6.2	Setup Description	210
8.7	Noise Characterization	212
8.7.1	Noise Parameter Measurement	212
8.7.2	Noise Parameter Test Setup	215
8.8	Mixer Characterization	217
8.8.1	Measurement Setup	217
8.8.2	Experimental Procedure	220
	References	221
	Authors	225
	About the Book	227
	Index	229