

RF and Microwave

Transistor Oscillator Design

ANDREI GREBENNIKOV

 **WILEY**



Contents

About the Author	ix
Preface	xi
Acknowledgements	xv
1 Nonlinear circuit design methods	1
1.1 Spectral-domain analysis	1
1.1.1 Trigonometric identities	2
1.1.2 Piecewise-linear approximation	4
1.1.3 Bessel functions	8
1.2 Time-domain analysis	9
1.3 Newton–Raphson algorithm	12
1.4 Quasilinear method	15
1.5 Van der Pol method	20
1.6 Computer-aided analysis and design	24
References	28
2 Oscillator operation and design principles	29
2.1 Steady-state operation mode	29
2.2 Start-up conditions	31
2.3 Oscillator configurations and historical aspects	36
2.4 Self-bias condition	43
2.5 Oscillator analysis using matrix techniques	50
2.5.1 Parallel feedback oscillator	50
2.5.2 Series feedback oscillator	53
2.6 Dual transistor oscillators	55
2.7 Transmission-line oscillator	60
2.8 Push–push oscillator	65
2.9 Triple-push oscillator	72
2.10 Oscillator with delay line	75
References	79

3 Stability of self-oscillations	83
3.1 Negative-resistance oscillator circuits	83
3.2 General single-frequency stability condition	86
3.3 Single-resonant circuit oscillators	87
3.3.1 Series resonant circuit oscillator with constant load	87
3.3.2 Parallel resonant circuit oscillator with nonlinear load	88
3.4 Double-resonant circuit oscillator	89
3.5 Stability of multi-resonant circuits	91
3.5.1 General multi-frequency stability criterion	91
3.5.2 Two-frequency oscillation mode and its stability	93
3.5.3 Single-frequency stability of oscillator with two coupled resonant circuits	94
3.5.4 Transistor oscillators with two coupled resonant circuits	96
3.6 Phase plane method	105
3.6.1 Free-running oscillations in lossless resonant LC circuits	106
3.6.2 Oscillations in lossy resonant LC circuits	108
3.6.3 Aperiodic process in lossy resonant LC circuits	110
3.6.4 Transformer-coupled MOSFET oscillator	112
3.7 Nyquist stability criterion	113
3.8 Start-up and stability	118
References	125
4 Optimum design and circuit technique	127
4.1 Empirical optimum design approach	128
4.2 Analytic optimum design approach	136
4.3 Parallel feedback oscillators	138
4.3.1 Optimum oscillation condition	138
4.3.2 Optimum MOSFET oscillator	139
4.4 Series feedback bipolar oscillators	142
4.4.1 Optimum oscillation condition	142
4.4.2 Optimum common base oscillator	143
4.4.3 Quasilinear approach	146
4.4.4 Computer-aided design	150
4.5 Series feedback MESFET oscillators	152
4.5.1 Optimum common gate oscillator	152
4.5.2 Quasilinear approach	154
4.5.3 Computer-aided design	157
4.6 High-efficiency design technique	162
4.6.1 Class C operation mode	162
4.6.2 Class E power oscillators	165
4.6.3 Class DE power oscillators	170
4.6.4 Class F mode and harmonic tuning	172
4.7 Practical oscillator schematics	177
References	182

5 Noise in oscillators	187
5.1 Noise figure	187
5.2 Flicker noise	196
5.3 Active device noise modelling	198
5.3.1 MOSFET devices	198
5.3.2 MESFET devices	200
5.3.3 Bipolar transistors	203
5.4 Oscillator noise spectrum: linear model	205
5.4.1 Parallel feedback oscillator	205
5.4.2 Negative resistance oscillator	214
5.4.3 Colpitts oscillator	216
5.5 Oscillator noise spectrum: nonlinear model	219
5.5.1 Kurokawa approach	219
5.5.2 Impulse response model	224
5.6 Loaded quality factor	235
5.7 Amplitude-to-phase conversion	239
5.8 Oscillator pulling figure	241
References	245
 6 Varactor and oscillator frequency tuning	 251
6.1 Varactor modelling	251
6.2 Varactor nonlinearity	255
6.3 Frequency modulation	258
6.4 Anti-series varactor pair	262
6.5 Tuning linearity	267
6.5.1 VCOs with lumped elements	267
6.5.2 VCOs with transmission lines	273
6.6 Reactance compensation technique	276
6.7 Practical VCO schematics	280
6.7.1 VCO implementation techniques	280
6.7.2 Differential VCOs	286
6.7.3 Push–push VCOs	292
References	296
 7 CMOS voltage-controlled oscillators	 299
7.1 MOS varactor	299
7.2 Phase noise	305
7.3 Flicker noise	310
7.4 Tank inductor	313
7.5 Circuit design concepts and technique	317
7.5.1 Device operation modes	317
7.5.2 Start-up and steady-state conditions	321
7.5.3 Differential cross-coupled oscillators	325
7.5.4 Wideband tuning techniques	326
7.5.5 Quadrature VCOs	331

7.6	Implementation technology issues	333
7.7	Practical schematics of CMOS VCOs	335
	References	342
8	Wideband voltage-controlled oscillators	347
8.1	Main requirements	347
8.2	Single-resonant circuits with lumped elements	351
	8.2.1 Series resonant circuit	351
	8.2.2 Parallel resonant circuit	353
8.3	Double-resonant circuit with lumped elements	356
8.4	Transmission line circuit realization	360
	8.4.1 Oscillation system with uniform transmission line	360
	8.4.2 Oscillation system with multi-section transmission line	365
8.5	VCO circuit design aspects	369
	8.5.1 Common gate MOSFET and MESFET VCOs	369
	8.5.2 Common collector bipolar VCO	373
	8.5.3 Common base bipolar VCO	376
8.6	Wideband nonlinear design	378
8.7	Dual mode varactor tuning	381
8.8	Practical RF and microwave wideband VCOs	387
	8.8.1 Wireless and satellite TV applications	387
	8.8.2 Microwave monolithic VCO design	391
	8.8.3 Push-push oscillators and oscipliers	394
	References	396
9	Noise reduction techniques	399
9.1	Resonant circuit design technique	399
	9.1.1 Oscillation systems with lumped elements	400
	9.1.2 Oscillation systems with transmission lines	402
9.2	Low-frequency loading and feedback optimization	410
9.3	Filtering technique	416
9.4	Noise-shifting technique	423
9.5	Impedance noise matching	426
9.6	Nonlinear feedback loop noise suppression	430
	References	433
	Index	437