
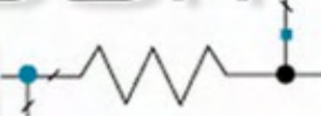



ROWAN GILMORE • LES BESSER

PRACTICAL 
RF CIRCUIT
DESIGN 
 FOR MODERN
WIRELESS
SYSTEMS

VOLUME II

ACTIVE CIRCUITS AND SYSTEMS

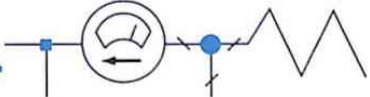




Practical RF Circuit Design for Modern Wireless Systems

Volume II

Active Circuits and Systems

ROWAN GILMORE • LES BESSER

PRACTICAL 
RF CIRCUIT
DESIGN 
 FOR MODERN
WIRELESS
SYSTEMS

VOLUME II

ACTIVE CIRCUITS AND SYSTEMS

Library of Congress Cataloging-in-Publication Data

Gilmore, Rowan.

Practical RF circuit design for modern wireless systems/Rowan Gilmore, Les Besser.

v. cm.—(Artech House microwave library)

Includes bibliographical references and index.

Contents: v. 2. Active circuits and systems

ISBN 1-58053-522-4 (v. 2: alk. paper)

1. Radio circuits—Design and construction. 2. Microwave circuits—Design and construction. 3. Wireless communication systems—Equipment and supplies.

I. Besser, Les. II. Title. III. Series.

TK6560.G45 2003

621.384'12—dc21

2003048107

British Library Cataloguing in Publication Data

Gilmore, Rowan

Practical RF circuit design for modern wireless systems

Vol. 2: Active circuits and systems.—(Artech House microwave library)

1. Radio circuits—Design 2. Wireless communication systems

I. Title II. Besser, Les

621.3'8412

ISBN 1-58053-522-4

Cover design by Yekaterina Ratner. Text design by Darrell Judd.

©2003 ARTECH HOUSE, INC.

685 Canton Street

Norwood, MA 02062

All rights reserved. Printed and bound in the United States of America. No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the publisher.

All terms mentioned in this book that are known to be trademarks or service marks have been appropriately capitalized. Artech House cannot attest to the accuracy of this information. Use of a term in this book should not be regarded as affecting the validity of any trademark or service mark.

International Standard Book Number: 1-58053-522-4

Library of Congress Catalog Card Number: 2003048107

10 9 8 7 6 5 4 3 2 1

To our wives, Nicole and Susan

Contents

Preface	xiii
Acknowledgments	xvii
1 Linear RF amplifier design— general considerations	1
1.1 Introduction	1
1.2 Power gain definitions	3
1.3 Neutralization	7
1.4 Unilateral transducer gain	8
1.4.1 Unilateral figure of merit	10
1.4.2 Illustrative example: unilateral gain calculations	12
1.4.3 Amplifier design with single matching networks	13
1.4.4 Unilateral constant gain circles	15
1.4.5 Illustrative example: single-sided amplifier design	15
1.5 RF circuit stability considerations	19
1.5.1 What may cause RF oscillation	22
1.5.2 Stability analysis with arbitrary source and load terminations	25
1.5.3 Two-port stability considerations	30
1.5.4 Stability circles	35
1.5.5 Graphical forms of unconditional stability	40
1.5.6 Graphical forms of potential instability	41
1.5.7 Caution about multistage systems	42
1.6 Stabilizing an active two-port	46
1.6.1 Finding the minimum-loss resistor at the input of the device	47
1.6.2 Broadband stability considerations	49
1.7 Stabilization of a bipolar transistor	50
1.7.1 Examining the effect of lossless feedback	50
1.7.2 Device stabilization	51
1.8 The dc bias techniques	59
1.8.1 Passive dc bias networks	60
1.8.2 Active dc bias circuits	63
1.8.3 Feeding dc bias into the RF circuit	64
1.8.4 The dc bias circuit simulation	65
1.8.5 Filtering of dc bias networks	69
1.9 Statistical and worst-case analyses	69

1.10	Circuit layout considerations	71
1.11	Summary	74
1.12	Problems	74
	References	75
	Selected bibliography	76
2	Linear and low-noise RF amplifiers	77
2.1	Introduction	77
2.2	Bilateral RF amplifier design for maximum small-signal gain	78
2.2.1	Illustrative exercise: amplifier design for maximum gain, G_{MAX}	82
2.3	Multistage amplifiers	88
2.3.1	Cascading impedance-matched stages	88
2.3.2	Cascading amplifiers by direct impedance matching	89
2.3.3	Output power and impedance match considerations of cascaded amplifiers	92
2.4	Operating gain design for maximum linear output power	94
2.4.1	Operating gain design outline	95
2.4.2	G_p versus P_{OUT} trade-offs	97
2.4.3	Stability considerations	97
2.4.4	Illustrative example: operating gain design for maximum linear power output	98
2.4.5	Output match considerations	101
2.5	Noise in RF circuits	102
2.5.1	Review of noise sources in RF systems	102
2.5.2	Two-port noise parameter definitions	106
2.6	Available gain design technique	107
2.6.1	Available gain design outline	108
2.6.2	Low-noise amplifier design considerations	110
2.6.3	Illustrative example: design of a single-ended 1.9-GHz LNA	111
2.6.4	Balanced amplifiers	114
2.6.5	Illustrative example: design of a balanced LNA for the 1.7- to 2.3-GHz frequency range	116
2.7	Comparison of the various amplifier designs and Smith chart-based graphical design aids	121
2.8	Broadband amplifiers	123
2.8.1	Reactive match/mismatch approach	124
2.8.2	Dissipative mismatch at input and/or output ports	125
2.8.3	Amplifier-equalizer combinations	129
2.8.4	Feedback amplifiers	129
2.8.5	Distributed amplifiers	141
2.9	Summary	142
2.10	Problems	143
	References	144
	Selected bibliography	145

3	Active RF devices and their modeling	147
3.1	The diode model	148
3.2	Two-port device models	150
3.2.1	The output terminals of a two-port RF device	150
3.2.2	The bipolar transistor	153
3.2.3	The heterojunction bipolar transistor	173
3.2.4	The GaAs MESFET	177
3.2.5	The high-electron mobility transistor	184
3.2.6	Silicon LDMOS and CMOS technologies	187
3.3	Problems	190
	References	190
4	Nonlinear circuit simulation techniques	193
4.1	Classification of nonlinear circuit simulators	193
4.1.1	Analytical methods	194
4.1.2	Time-domain methods	194
4.1.3	Hybrid time- and frequency-domain techniques— harmonic balance	197
4.1.4	Frequency-domain techniques	200
4.2	The harmonic balance method	202
4.3	Harmonic balance analysis of oscillators	207
4.3.1	Oscillator analysis using probes	208
4.3.2	Oscillator analysis using reflection coefficients of the device and resonant load	209
4.3.3	Oscillator analysis using a directional coupler to measure open-loop gain	214
	References	215
5	High-power RF transistor amplifier design	217
5.1	Nonlinear concepts	217
5.1.1	Some nonlinear phenomena	220
5.2	Quasi-linear power amplifier design	223
5.2.1	The amplifier load line	224
5.2.2	Load pull methods	232
5.3	Categories of amplifiers	243
5.3.1	Class-A amplifier	243
5.3.2	Class-B amplifier	248
5.3.3	Class-F amplifier	257
5.3.4	Comparison of class-A, class-B, class-F, and other operational modes	265
5.3.5	Switching-mode amplifiers	271
5.3.6	Cascaded power amplifier design	278

5.4	Power amplifier design example	280
5.4.1	Transistor selection	281
5.4.2	Transistor characterization	282
5.4.3	Matching the input and output of the device	286
5.4.4	Harmonic tuning example	296
5.5	Bias considerations	298
5.5.1	Bias changes at the input	298
5.5.2	Bias changes at the output	302
5.5.3	Bias considerations with power devices	304
5.6	Distortion reduction	307
5.6.1	The importance of amplifier linearity	309
5.6.2	Operating the amplifier backed off	311
5.6.3	Predistortion	312
5.6.4	Feedforward cancellation	317
5.6.5	Device modification	319
5.6.6	System-level reduction of distortion	325
5.7	Problems	328
	References	334
6	Oscillators	337
6.1	Principles of oscillator design	338
6.1.1	Two-port oscillator design approach	338
6.1.2	One-port oscillator design approach	349
6.1.3	Transistor oscillator configurations	373
6.1.4	Characterizing oscillator phase noise	390
6.2	Oscillator design examples	404
6.2.1	45.455-MHz Colpitts crystal oscillator design	404
6.2.2	Design of a 3.7- to 4.2-GHz voltage-controlled oscillator	410
6.3	Problems	429
	References	431
7	Mixers and frequency multipliers	433
7.1	Mixer overview and their applications in systems	433
7.2	Diode mixers and their topologies	442
7.2.1	Single-ended mixer	443
7.2.2	Single-balanced mixer	445
7.2.3	Double-balanced mixer	451
7.2.4	The image problem in mixers	455
7.2.5	Harmonic components in mixers	460
7.3	Transistor mixer design	464
7.3.1	Active transistor mixers	464
7.3.2	Resistive FET mixers	488
7.3.3	Dual-gate FET mixers	494
7.3.4	Comparison of mixers	500