mobile communications series

SOFTWARE-DEFINED RADIO for ENGINEERS

TRAVIS F. COLLINS
ROBIN GETZ
DI PU
ALEXANDER M. WYGLINSKI

Software-Defined Radio for Engineers

For a listing of recent titles in the *Artech House Mobile Communications*, turn to the back of this book.

Software-Defined Radio for Engineers

Travis F. Collins
Robin Getz
Di Pu
Alexander M. Wyglinski

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the U.S. Library of Congress.

British Library Cataloguing in Publication Data
A catalog record for this book is available from the British Library.

ISBN-13: 978-1-63081-457-1

Cover design by John Gomes

10 9 8 7 6 5 4 3 2 1

Dedication

To my wife Lauren
—Travis Collins

To my wonderful children, Matthew, Lauren, and Isaac, and my patient wife, Michelle—sorry I have been hiding in the basement working on this book. To all my fantastic colleagues at Analog Devices: Dave, Michael, Lars-Peter, Andrei, Mihai, Travis, Wyatt and many more, without whom Pluto SDR and IIO would not exist.
—Robin Getz

To my lovely son Aidi, my husband Di, and my parents Lingzhen and Xuexun
—Di Pu

To my wife Jen
—Alexander Wyglinski

Contents

APPENDIX D

Trigonometric Identities

$$\exp(\pm j\theta) = \cos(\theta) \pm j\sin(\theta)$$

$$\cos(\theta) = \frac{1}{2}[\exp(j\theta) + exp(-j\theta)]$$

$$\sin(\theta) = \frac{1}{2j}[\exp(j\theta) - \exp(-j\theta)]$$

$$\sin^2(\theta) + \cos^2(\theta) = 1$$

$$\cos^2(\theta) - \sin^2(\theta) = \cos(2\theta)$$

$$\cos^2(\theta) = \frac{1}{2}[1 + \cos(2\theta)]$$

$$\sin^2(\theta) = \frac{1}{2}[1 - \cos(2\theta)]$$

$$2\sin(\theta)\cos(\theta) = \sin(2\theta)$$

$$\sin(\alpha \pm \beta) = \sin(\alpha)\cos(\beta) \pm \cos(\alpha)\sin(\beta)$$

$$\cos(\alpha \pm \beta) = \cos(\alpha)\cos(\beta) \mp \sin(\alpha)\sin(\beta)$$

$$\tan(\alpha \pm \beta) = \frac{\tan(\alpha) \pm \tan(\beta)}{1 \mp \tan(\alpha)\tan(\beta)}$$

$$\sin(\alpha)\sin(\beta) = \frac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)]$$

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}[\cos(\alpha - \beta) + \cos(\alpha + \beta)]$$

$$\sin(\alpha)\cos(\beta) = \frac{1}{2}[\sin(\alpha - \beta) + \sin(\alpha + \beta)]$$