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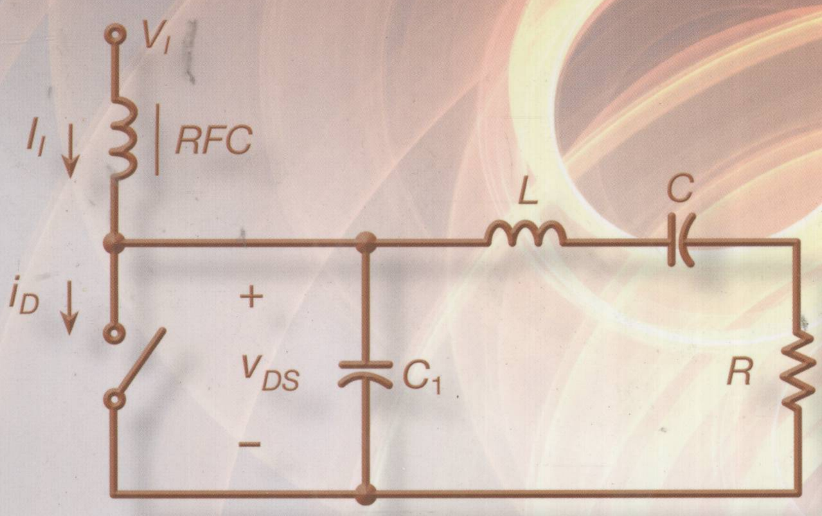
MARIAN K. KAZIMIERCZUK



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WILEY
A John Wiley and Sons, Ltd., Publication

This edition first published 2008

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data

Kazimierczuk, Marian.
RF power amplifiers / Marian K. Kazimierczuk.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-77946-0 (cloth)
1. Power amplifiers. 2. Amplifiers, Radio frequency. I. Title.
TK7871.58.P6K39 2008
621.384′12 – dc22

2008032215

A catalogue record for this book is available from the British Library.

ISBN: 978-0-470-77946-0 (H/B)

Typeset by Laserwords Private Limited, Chennai, India
Printed and bound in Great Britain by CPI Antony Rowe, Chippenham, Wiltshire

RF Power Amplifiers

To My Mother

Preface

This book is about RF power amplifiers used in wireless communications and many other RF applications. It is intended as a concept-oriented textbook at the senior and graduate levels for students majoring in electrical engineering, as well as a reference for practicing engineers in the area of RF power electronics. The purpose of the book is to provide foundations for RF power amplifiers, efficiency improvement, and linearization techniques. Class A, B, C, D, E, DE, and F RF power amplifiers are analyzed and design procedures are given. Impedance transformation is covered. Various linearization techniques are explored, such as predistortion, feedforward, and negative feedback techniques. Efficiency improvement methods are also studied, such as envelope elimination and restoration, envelope tracking, Doherty amplifier, and outphasing techniques. Integrated inductors are also studied.

The textbook assumes that the student is familiar with general circuit analysis techniques, semiconductor devices, linear systems, and electronic circuits. A communications course is also very helpful.

I wish to express my sincere thanks to Simone Taylor, Publisher, Engineering Technology, Jo Bucknall, Assistant Editor, and Erica Peters, Content Editor. It has been a real pleasure working with them. Last but not least, I wish to thank my family for the support.

I am pleased to express my gratitude to Nisha Das for the MATLAB figures. The author would welcome and greatly appreciate suggestions and corrections from readers, for improvements in the technical content as well as the presentation style.

Marian K. Kazimierczuk

About the Author

Marian K. Kazimierczuk is Professor of Electrical Engineering at Wright State University, Dayton, Ohio, USA. He is the author of five books, over 130 journal papers, over 150 conference papers, and seven patents. He is a Fellow of the IEEE and he received an Outstanding Teacher Award from the American Society for Engineering Education in 2008. His research interests are in the areas of RF power amplifiers, radio transmitters, power electronics, PWM dc-dc power converters, resonant dc-dc power converters, modeling and controls, semiconductor power devices, magnetic devices, and renewable energy sources.

List of Symbols

a	Coil mean radius
A_e	Effective area of antenna
A_v	voltage gain
B	Magnetic flux density
BW	Bandwidth
c_p	Output-power capability of amplifier
C	Resonant capacitance
C_c	Coupling capacitance
C_{ds}	Drain-source capacitance of MOSFET
$C_{ds(25V)}$	Drain-source capacitance of MOSFET at $V_{DS} = 25$ V
C_f	Filter capacitance
C_{fmin}	Minimum value of C_f
C_{gd}	Gate-drain capacitance of MOSFET
C_{gs}	Gate-source capacitance of MOSFET
C_{iss}	MOSFET input capacitance at $V_{DS} = 0$, $C_{iss} = C_{gs} + C_{gd}$
C_{oss}	MOSFET output capacitance at $V_{GD} = 0$, $C_{oss} = C_{gs} + C_{ds}$
C_{ox}	Oxide capacitance per unit area
C_{out}	Transistor output capacitance
C_{rss}	MOSFET transfer capacitance, $C_{rss} = C_{gd}$
C_B	Blocking capacitance
d	Coil inner diameter
D	Coil outer diameter
E	Electric field intensity
f	Operating frequency, switching frequency
f_c	Carrier frequency
f_{IF}	Intermediate frequency
f_{LO}	Local oscillator frequency
f_m	Modulating frequency
f_o	Resonant frequency
f_p	Frequency of pole of transfer function
f_r	Resonant frequency of L-C-R circuit
f_s	Switching frequency
g_m	Transconductance of transistor

H	Magnetic flux intensity
h	Trace thickness
i	Current
iC	Capacitor current
I_D	DC drain current
i_D	Large-signal drain current
i_d	Small-signal drain current
i_L	Inductor current
i_o	Ac output current
i_S	Switch current
I_m	Amplitude of current i
I_{rms}	Rms value of i
I_{DM}	Peak drain current
I_{SM}	Peak current of switch
J_n	Bessel's function of first kind and n-th order
K	MOSFET parameter
k_p	Power gain
l	Trace length, Winding length
L	Resonant inductance, channel length
L_f	Filter inductance
L_{fmin}	Minimum value of L_f
m	Modulation index
m_f	Index of frequency modulation
m_p	Index of phase modulation
N	Number of inductor turns
n	Transformer turns ratio
p	Perimeter enclosed by coil
P_G	Gate drive power
p_r	Power loss in resonant circuit
P_{tf}	Average power loss due to current fall time t_f
P_{AM}	Power of AM signal
P_C	Power of carrier
P_{LS}	Power of lower sideband
P_{Loss}	Power loss
P_D	Power dissipation
P_I	Dc supply (input) power
P_O	Ac output power
P_{US}	Power of upper sideband
$p_D(\omega t)$	Instantaneous drain power loss
Q_o	Unloaded quality factor at f_o
Q_{oL}	Quality factor of inductor
Q_L	Loaded quality factor at f_o
r	Total parasitic resistance
r_C	ESR of filter capacitor
r_{DS}	On-resistance of MOSFET
R	Overall resistance of amplifier
R_{DC}	DC input resistance of Amplifier
r_G	Gate resistance
R_L	Dc load resistance
R_{Lmin}	Minimum value of R_L

r_o	Ouput resistance of transistor
s	Trace-to-trace spacing
S_i	Current slope
S_v	Voltage slope
T	Operating temperature
THD	Total harmonic distortion
V_A	Channel-modulation voltage
v	Voltage
V_{DS}	DC drain-source voltage
V_{dsm}	Amplitude of small-signal drain-source voltage
v_{DS}	Large-signal drain-source voltage
v_{ds}	Small-signal drain-source voltage
V_{GS}	DC gate-source voltage
v_{GS}	Large-signal gare-source voltage
V_{gm}	Amplitude of small-signal gate-source voltage
v_{gs}	Small-simal gate-source voltage
v_m	Modulating voltage
v_c	Carrier voltage
v_m	Modulating voltage
v_o	Ac output voltage
V_c	Amplitude of carrier voltage
V_m	Amplitude of modulating voltage
V_m	Amplitude of voltage
V_n	n-th harmonic of the output voltage
V_{Cm}	Amplitude of the voltage across capacitance
V_{DS}	DC drain-source voltage
v_{DS}	Large-signal drain-source voltage
v_{ds}	Small-signal drain-source voltage
V_I	DC supply (input) voltage
V_{Lm}	Amplitude of the voltage across inductance
V_{DSM}	Peak voltage of switch
V_{rms}	Rms value of v
V_t	Threshold voltage of MoSFET
w	Trace width
W	Energy, channel width
X	Imaginary part of Z
Z	Input impedance of resonant circuit
Z_i	Input impedance
$\|Z\|$	Magnitude of Z
Z_o	Characteristic impedance of resonant circuit
α_n	Fourier coefficients of drain current
β	Gain of feedback network
δ	Dirac impulse function
Δf	Frequency deviation
ϵ_{ox}	Oxide permittivity
η	Efficiency of amplifier
η_{AV}	Average efficiency
η_D	Drain efficiency
η_r	Efficiency of resonant circuit
η_{PAE}	Power-aided efficiency

λ	Wavelength, channel length-modulation parameter
μ_0	Permeability of fee space
μ_n	Mobility of electrons
μ_r	Relative permeability
ρ	Resistivity
σ	Conductivity
ξ_n	Fourier coefficients of drain-source voltage
γ_n	Ratio Fourier coefficients of drain current
Φ	Phase, angle, magnetic flux
θ	Half of drain current conduction angle, mobility degration coefficient
ω	Operating angular frequency
ω_c	Carrier angular frequency
ω_m	Modulating angular frequency
ω_o	Resonant angular frequency

Contents