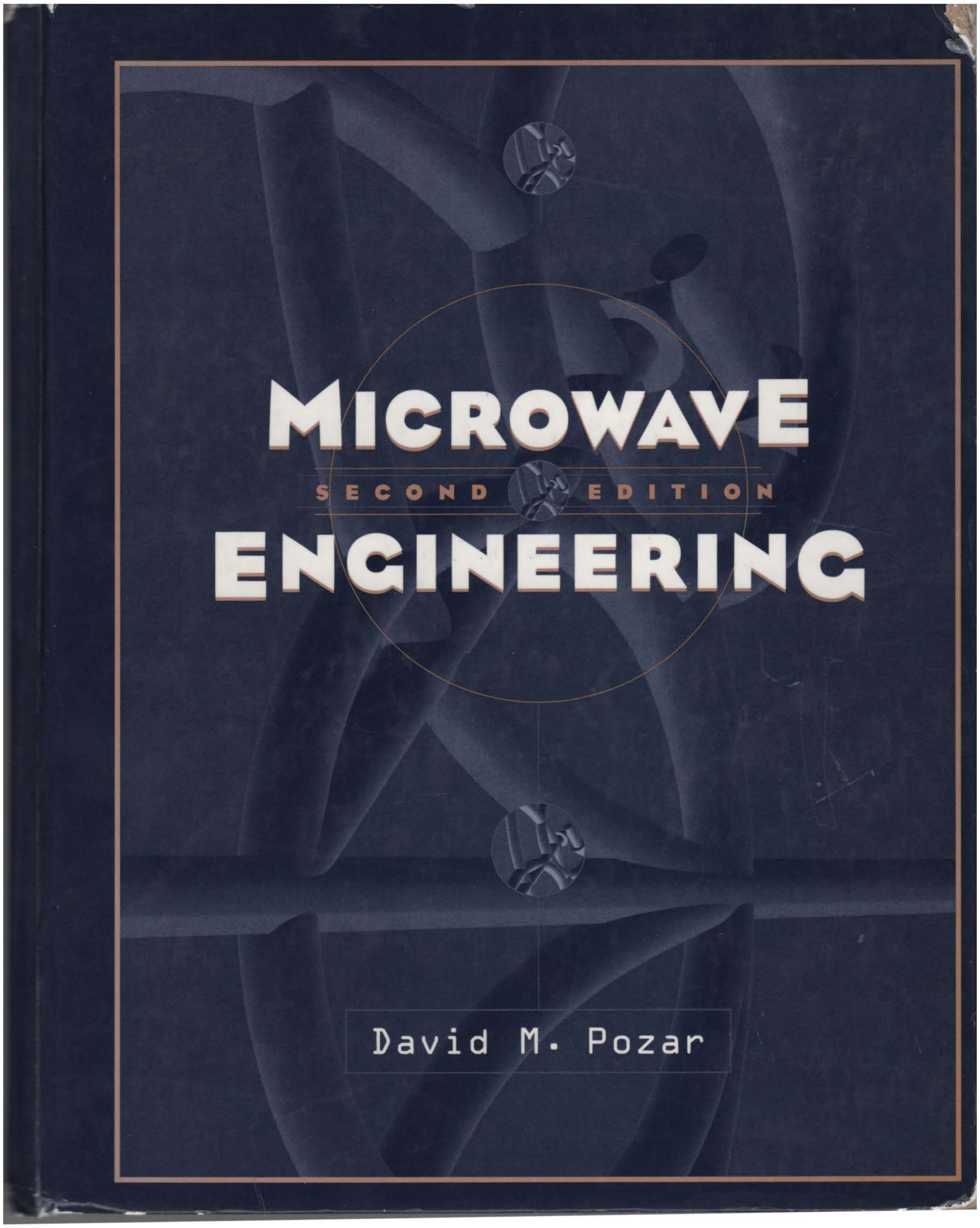
MICROWAVE
SECOND EDITION
ENGINEERING
David M. Pozar

EXECUTIVE EDITOR Charity Robey
EDITORIAL ASSISTANT Susanne Dwyer
MARKETING MANAGER Harper Mooy
SENIOR PRODUCTION MANAGER Lucille Buonocore
SENIOR PRODUCTION EDITOR Monique Calello
COVER DESIGNER David Levy
ILLUSTRATION STUDIOS Wellington & Vantage Art
ILLUSTRATION COORDINATOR Gene Aiello
MANUFACTURING MANAGER Monique Calello

This book was set in 10/12 Times Roman by ETP HARRISON and printed and bound by R.R. Donnelley & Sons Company, Crawfordsville. The cover was printed by The Lehigh Press, Inc.

Recognizing the importance of preserving what has been written, it is a policy of John Wiley & Sons, Inc. to have books of enduring value published in the United States printed on acid-free paper, and we exert our best efforts to that end.

The paper on this book was manufactured by a mill whose forest management programs include sustained yield harvesting of its timberlands. Sustained yield harvesting principles ensure that the number of trees cut each year does not exceed the amount of new growth.

Library of Congress Cataloging in Publication Data

Pozar, David M.
Microwave engineering / David M. Pozar. -- 2nd ed.
p. cm.
ISBN 0-471-17096-8 (cloth : alk. paper)
1. Microwaves. 2. Microwave devices. 3. Microwave circuits.
I. Title.
TK7876.P69 1998
621.381'3--dc20 97-20878
CIP

Printed in the United States of America

10 9 8 7 6 5 4

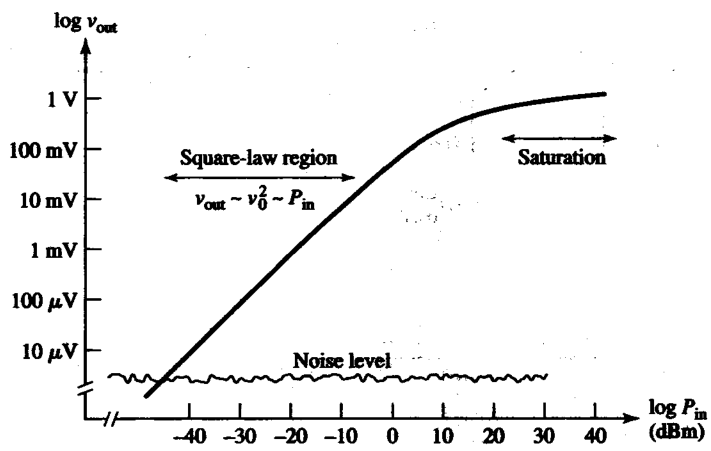

FIGURE 10.15 Square-law region for a typical diode detector.

Single-Ended Mixer

A mixer uses the nonlinearity of a diode to generate an output spectrum consisting of the sum and difference frequencies of two input signals. In a receiver application, a low-level RF signal and an RF local oscillator (LO) signal are mixed together to produce an intermediate frequency (IF), $f_{IF} = f_{RF} - f_{LO}$, and a much higher frequency, $f_{RF} + f_{LO}$, which is filtered out. See Figure 10.16a. The IF signal usually has a frequency between 10 and 100 MHz, and can be amplified with a low-noise amplifier. This is called a heterodyne receiver, and is useful because it has much better sensitivity and noise characteristics (using an IF amplifier minimizes $1/f$ noise) than the direct detection scheme discussed in the previous section. A heterodyne system also has the advantage of being able to tune over a band by simply changing the LO frequency, without the need for a high-gain, wideband RF amplifier.

As shown in Figure 10.16b, a mixer can also be used in a transmitter to offset the frequency of an RF signal by an amount equal to f_{IF}. This is a convenient technique, as it allows the use of identical local oscillators in the transmitter and receiver; a single oscillator may serve this purpose in a radar or transceiver system.

There are several types of mixer circuits, but the simplest is the *single-ended mixer*; single-ended mixers often are used as part of more sophisticated mixers. A typical single-ended mixer circuit is shown in Figure 10.17, where an RF signal,

$$v_{RF}(t) = v_r \cos \omega_r t, \tag{10.36}$$

is combined with an LO signal,

$$v_{LO}(t) = v_0 \cos \omega_0 t, \tag{10.37}$$

and fed into a diode. The combiner may be a simple T-junction combiner, or a directional coupler. An RF matching circuit may precede the diode, and the diode may be biased through chokes that allow DC to pass while blocking RF. From (10.29), the diode current

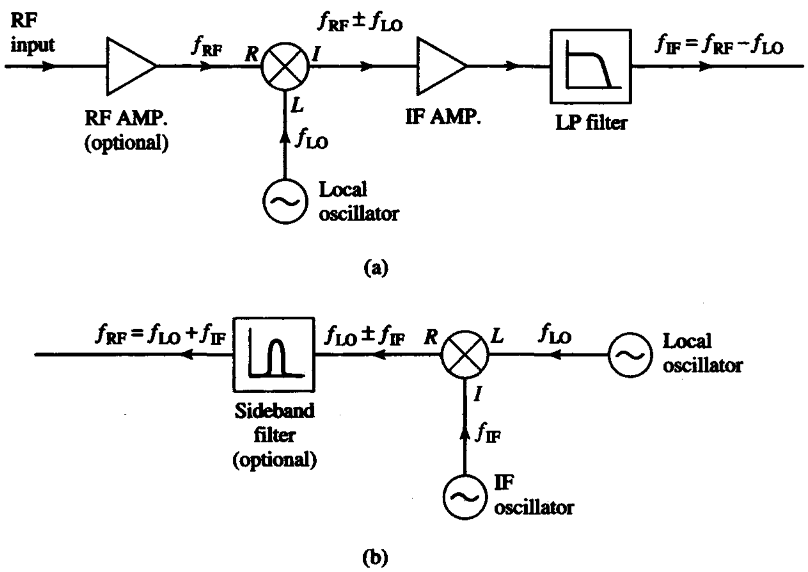

FIGURE 10.16 Frequency conversion in a receiver and transmitter. (a) Down-conversion in a heterodyne receiver. (b) Up-conversion in a transmitter.

will consist of a constant DC bias term, and RF and LO signals of frequencies ω_r and ω_0, due to the term which is linear in v. The v^2 term will give rise to the following output current:

$$i = \frac{G'_d}{2}(v_r \cos \omega_r t + v_0 \cos \omega_0 t)^2$$

$$= \frac{G'_d}{2}(v_r^2 \cos {}^2\omega_r t + 2v_r v_0 \cos \omega_r t \cos \omega_0 t + v_0^2 \cos {}^2\omega_0 t)$$

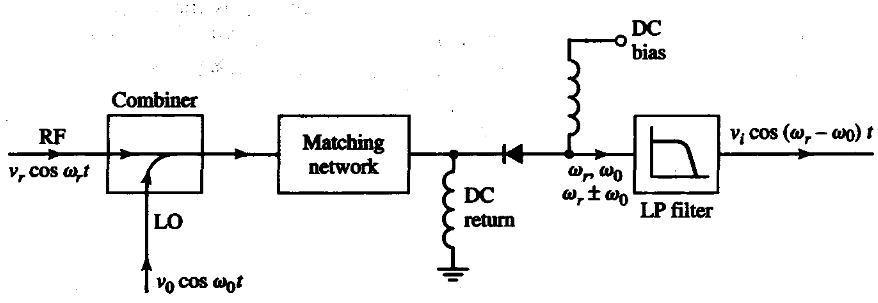

FIGURE 10.17 Single-ended mixer circuit.

$$= \frac{G_d'}{4}[v_r^2 + v_0^2 + v_r^2 \cos 2\omega_r t + v_0^2 \cos 2\omega_0 t$$
$$+ 2v_r v_0 \cos(\omega_r - \omega_0)t + 2v_r v_0 \cos(\omega_r + \omega_0)t]. \qquad 10.38$$

The DC terms can be ignored, and the $2\omega_r$ and $2\omega_0$ terms will be filtered out. The most important terms are those of frequency $\omega_r \pm \omega_0$.

For a receiver or down-converter, the $\omega_r - \omega_0$ term will become the IF signal. Note that, for a given local oscillator frequency, there will be two RF frequencies that will mix down to the same IF frequency. If the RF frequency is $\omega_r = \omega_0 + \omega_i$, then the output frequencies of the mixer will be $\omega_r \pm \omega_0 = 2\omega_0 + \omega_i$, and ω_i; if the RF frequency is $\omega_r = \omega_0 - \omega_i$, the mixer output frequencies will be $\omega_r \pm \omega_0 = 2\omega_0 - \omega_i$, and $-\omega_i$. This latter output is called the *image response* of the mixer, and is indistinguishable from the direct response. It can be eliminated by RF filtering at the input of the mixer, but this is difficult because the desired RF frequency $(\omega_0 + \omega_i)$ is relatively close to the spurious image frequency at $(\omega_0 - \omega_i)$, since generally $\omega_i << \omega_0$. Another way to eliminate the image response is by using an image rejection mixer.

In an up-converter, or modulation, application the two inputs will usually be a local oscillator and an IF oscillator, as in Figure 10.16b. The IF signal would be modulated with the desired information signal. Then the output will be $\omega_0 \pm \omega_i$, where ω_i is the IF frequency. The frequency $\omega_0 + \omega_i$ is called the *upper sideband* (USB), while $\omega_0 - \omega_i$ is called the *lower sideband* (LSB). Double sideband (DSB) modulation retains both sidebands, while single sideband (SSB) modulation removes one of the sidebands by filtering or by using an image rejection mixer (also called a single sideband modulator).

Mixer design involves impedance matching the three ports, which is complicated by the fact that several frequencies and their harmonics are involved. Undesired harmonic power can be dissipated in resistive terminations, or blocked with reactive terminations. Resistive loads increase the loss of the mixer, and reactive loads are usually very frequency sensitive. An important figure of merit for a mixer is the *conversion loss*, defined as

$$L_C = 10 \log \frac{\text{available RF input power}}{\text{IF output power}} \text{ dB}. \qquad 10.39$$

Practical mixers usually have a conversion loss between 4 and 7 dB. One factor that strongly affects the conversion loss of a mixer is the local oscillator signal (or *pump*) power level; minimum conversion loss usually occurs for LO powers between 0 and 10 dBm. This power level is large enough to violate the small-signal approximation of (10.29), so results using such a model may not be very accurate. Precise design requires numerical solution of the nonlinear equation that describes the diode characteristics [4].

Because a mixer is often the first or second component in a receiver system, its noise characteristics can be of critical importance. When specifying the noise figure of a mixer (or a receiver that uses a mixer), a distinction must be made as to whether the input is a single sideband signal or a double sideband signal. This is because the mixer will produce an IF output for two RF frequencies $(\omega_0 \pm \omega_i)$, and therefore collect noise power at both frequencies. When used with a DSB input, the mixer will have desired signals at both RF frequencies, while an SSB input provides the desired signal only at one of these frequencies. Thus the DSB noise figure will be 3 dB lower than the SSB noise figure.