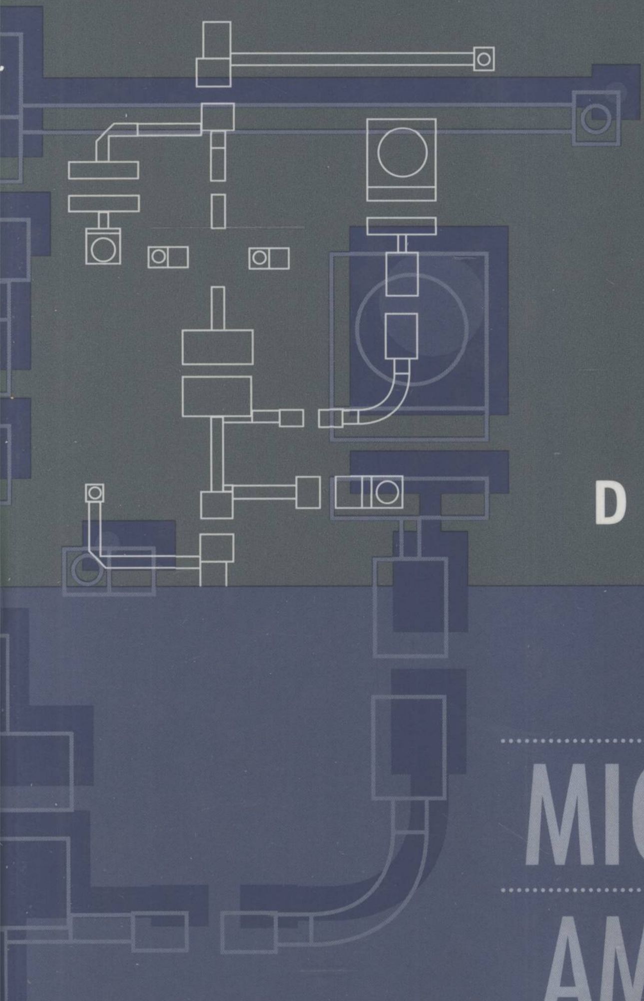
PIETER L.D. ABRIE



DESIGN OF RF AND MICROWAVE AMPLIFIERS AND OSCILLATORS

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Design of RF and Microwave Amplifiers and Oscillators

Pieter L.D. Abrie

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To my wife, Hilda,

and

our sons, Albert, Dewald, and Willem

PREFACE

In this book the design of radio-frequency and microwave amplifiers and oscillators is addressed. The focus is on iterative synthesis techniques. The design of small-signal, class A, and class B amplifiers is considered.

Because impedance-matching is a major part of amplifier design and the purpose is to cover amplifier design comprehensively, all the material in [1] is also included in this book. Where necessary, this material has been revised and extended. Upgraded and extended versions of the main computer programs provided as text listings in [1] are provided with this book on diskette, in both source code and executable format.

A main feature of this book is the introduction of a generalized approach to estimate the output power (1-dB compression point) of a linear amplifier without resorting to non-linear analysis techniques. The small-signal model and four boundary lines on the dc *I*/*V*-curves of each transistor are used in this approach. All the normal operations associated with the *S*-parameters and the noise parameters of a linear circuit (feedback, loading, cascading, changes in configuration) are also allowed with the proposed power parameters. The basic principle in this approach is that the output power of a transistor is mainly limited by clipping of the intrinsic current or voltage. Clipping (voltage clipping) has always been used in designing RF power amplifiers. Application of this principle at microwave frequencies was first illustrated in [2].

The purpose of the power parameter approach is not to exclude nonlinear analysis of the circuit (assuming that accurate nonlinear models are available), but to control the output power during the synthesis phase. However, it should be mentioned that if the theoretical harmonic and intermodulation performance of a circuit are not of interest, the results obtainable with the power parameter approach are usually adequate. Because of its accuracy, the power parameters can also be used to initialize the fundamental tone voltages in a harmonic balance simulator (class A, class AB, and class B stages).

The external load associated with any intrinsic load can be found easily by using the power parameter approach. With this capability in place, it is a simple matter to generate load-pull contours for any linear amplifier stage.

At the time [1] was published, amplifier design was considered to essentially reduce to the design of specialized impedance-matching networks. However, it was found that when more demanding amplifiers are designed (low input VSWR and low noise; high dynamic range; low output VSWR and high power), the performance could only be obtained by modifying the characteristics of the transistors used with frequency-selective resistive networks (feedback and/or loading). In doing this, the excess in capability (noise figure, gain) at the lower frequencies is exchanged for more desirable characteristics (stability, gain leveled in the passband, improved VSWRs, optimum noise/power and optimum match points closer to each other, ...) in the passband of interest. This class of action will be referred to as device-modification.

Because of the desensitizing effect of the resistive networks added, it was found that amplifiers based on device-modification and impedance-matching are frequently first-time-right. It was also found that choosing the right transistors for an amplifier can be critical in this respect. While transistors may seem to be equivalent on superficial inspection, the performance obtainable during the device-modification stage may differ greatly.

The normal approach to deciding on the stability of an amplifier was also found to be inadequate in some cases. Small changes in some circuits can easily change them from inherently stable to potentially (or actually) unstable. Satisfactory results were obtained when the stability analysis was extended to include calculation of the well-known gain and phase margins used in feedback theory. Because the actual cause of the oscillations are usually the feedback loops introduced, it makes sense to investigate these loops in addition to calculating the usual "black-box"stability factors. Knowing that a loop is 1 dB away from oscillation also contains much more information than just knowing the k factor for a circuit.

The loop gain approach also leads directly to the design of RF and microwave oscillators. Knowing the loop gain, in addition to the other stability factors, provides a much clearer picture of the stability situation.

A major shortcoming in the regular approach to the design of oscillators is that only the negative resistance is considered during synthesis. Clearly, clipping of the voltage and current is as important as in the case of amplifiers. In the design approach proposed here, the loop gain is controlled with the load line presented to the transistor used. An immediate advantage of a well-behaved load line is that the main nonlinear effect in the oscillator will be g_m compression. Assuming an exponential saturation curve for the output power, the loop gain can then be controlled to maximize the output power of the oscillator. If low phase noise is required, the loop gain must be kept low in order to minimize upconversion of the flicker noise.

The optimum load termination for the transistor used in an oscillator can also be obtained by using the power parameter approach.

Impedance-matching by using "real-frequency" techniques is well established at this point in time. To be of real practical use at microwave frequencies, it is essential to design a matching network with the pads required for any lumped components in place. The transformation Q technique described here can easily be extended to provide this capability. The same approach can be used to design mixed lumped/distributed matching networks in which the lumped components are used to reduce the line lengths required.

Single-layer parallel plate capacitors and metal-insulator-metal (MIM) capacitors are frequently used in microwave matching networks. To properly allow for their effect during synthesis, their distributed nature should be understood. Accurate modeling of these capacitors is, therefore, also considered here.

The material in this book is organized as follows.

Analysis and characterization of RF and microwave circuits with Y-, Z-, T-, and S-parameters are considered in Chapter 1. Analysis by using flow diagrams is also considered. Characterization and analysis of the noise and the power performance of active circuits are considered in Chapter 2. Noise correlation matrices are introduced with the power parameter approach.

Radio-frequency components are considered in Chapter 3. Basic inductor, capacitor, and resistor models are considered, with the skin-effect and the proximity effect. The design of single-layer air-cored inductors, and inductors with magnetic cores, is investigated in detail. Coaxial cables and microstrip transmission lines are also considered in this chapter. Resonant circuits and the design of narrowband impedance-matching networks (L-, T-, and PI-sections) are investigated in Chapter 4. Coupled coils and conventional transformers are covered in Chapter 5. Transmission-line transformers are covered in Chapter 6. The design of RF power amplifiers is also considered in this chapter. Film resistors and single-layer parallel-plate capacitors are considered in Chapter 7. Chapter 8 is devoted to the design of wideband impedance-matching networks. Microwave lumped elements, and distributed equivalents for inductors and capacitors, are covered in Chapter 9, with the parasitic effects of microstrip discontinuities at the lower microwave frequencies (up to X-band). The design of RF and microwave amplifiers and oscillators is considered in Chapter 10. The design of cascade amplifiers, lossless feedback amplifiers, reflection amplifiers, and balanced amplifiers is considered in this chapter.

This book was prepared in camera-ready format and a massive amount of this work was done by my wife, Hilda. I would like to acknowledge her contributions to this book at this point. I would also like to acknowledge the significant contributions of the reviewer to this book. Finally, I would like to express my appreciation to the Artech House team for their professional handling of this project.

Pieter L.D. Abrie
Somerset West
April 1999

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