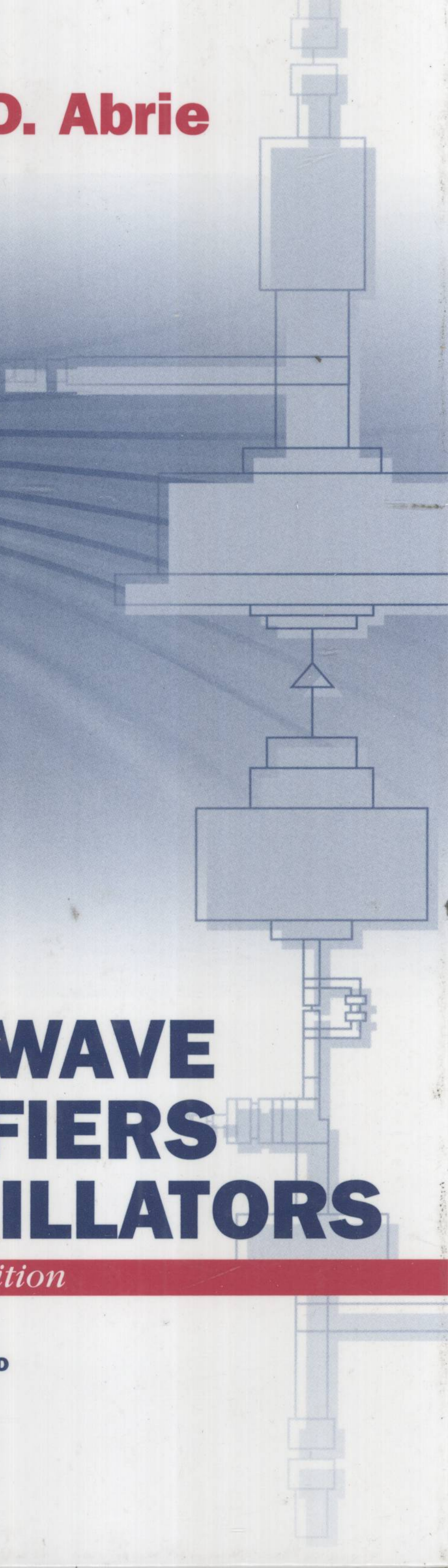
Pieter L. D. Abrie



Design of RF *and* MICROWAVE AMPLIFIERS *and* OSCILLATORS

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Design of RF and Microwave Amplifiers and Oscillators

Second Edition

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 will be on synthesis techniques (iterative, as well as analytical) for designing linear amplifiers. Class A, class B, class AB, class E (not linear), class F, and Doherty amplifiers will be considered. The design of small-signal amplifiers, including low-noise amplifiers, will also be considered in detail.

Most of the material covered previously in [1, 2] is also included in this book. Where necessary, the material has been revised and extended. The executable of a new integrated version (LSM) of the main computer programs provided previously is also licensed with this book. The new program is a Visual C++ 2008 program with a menu driven interface. This program will run under Windows Vista and Windows XP. The Fortran source code of the previous versions are also supplied with the book. Wideband single-, as well as double-matching (complex source and complex load) problems can be solved with LSM. A wizard for fitting a resistance (conductance) function to a set of resistance versus frequency data points is also provided in LSM.

To be of real practical use at microwave and millimeter-wave frequencies, it is essential to design a matching network with the pads required for any lumped components in place. The transformation-*Q* technique described 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. Matching networks with spiral inductors and parallel-plate (MIM) capacitors can also be designed directly by following this approach. In order to do this, accurate modeling of spiral inductors and parallel-plate capacitors is required. Modeling of these components will also be considered in this book.

A main feature of this book remains the power parameter approach introduced in [2] to estimate the output power (1-dB compression point) of a linear amplifier without resorting to nonlinear analysis techniques. Apart from the advantage that close to optimum designs can be created in many cases without load-pull information or an accurate large-signal model, the power parameter approach also serves to generate solutions that can be refined in nonlinear circuit simulators.

The basic principle in the power parameter approach is that the output power of a linear amplifier is limited by the maximum amplitudes of the current and voltage associated with the intrinsic current-source in the transistor model [3]. The output power extracted from a transistor can be current- and/or voltage-limited. Harmonics can complicate or improve the situation. In a class-F amplifier, the square (ideal case) voltage waveform allows the fundamental tone voltage-swing to be larger than the supply voltage (minus the knee voltage), with a corresponding increase in power. The square waveform also increases the efficiency.

A small-signal model, the dc operating point (at full power), and four boundary lines on the dc or pulsed *I*/*V*-curves of each transistor used are required in this approach. The power parameters of the transistor can be derived from the small-signal model. 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 power parameters.

The external load line associated with any intrinsic load line 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, and to find the external terminations associated with the required intrinsic harmonic terminations.

The idea that amplifier design essentially reduces to the design of specialized impedance-matching networks is still prevalent. However, it was found that when more demanding amplifiers, especially wideband amplifiers, are designed, 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 in the passband of interest (stability, gain leveled in the passband, reduced gain-bandwidth constraints, and correspondingly, improved VSWRs (voltage standing wave ratios), and optimum noise/power and optimum match points closer to each other). This preconditioning step 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 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 in some cases 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 is often 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 is also useful.

When narrowband high power amplifiers are designed it may not be realistic to add modification networks to a transistor. Measures and techniques for designing conditionally stable amplifiers are then required. Useful concepts like the maximum single-sided-matched stable gain, and the maximum mismatched (double-sided) stable gain were introduced in [4, 5]. Stability factors, introduced in [4–6], will indicate the range of reflection coefficients (VSWRs) that can be tolerated before the potential instability of a selected transistor results in oscillations. Note that these reflection coefficients are defined in terms of the default normalization resistance used (50Ω). These stability factors can be generalized by using the actual terminations of interest (generally, complex impedances) as normalization impedances, as was done in [7].

The power parameters approach combined with loop gain calculations also lead directly to the design of RF and microwave oscillators. 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. 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, and the loaded Q of the circuit must be maximized.

The material in this book is organized as follows.

Analysis and characterization of linear 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 linear circuits are considered in Chapter 2. Noise correlation matrices and the power parameters are also covered, with the load-line considerations applying to the different classes of linear power amplifiers. Doherty amplifiers are also considered.

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 also 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 widely used in RF and UHF circuits and are covered in Chapter 6. The design of RF power amplifiers is also considered in this chapter. Film resistors, single-layer parallel-plate capacitors (including MIM capacitors), spiral inductors, and microstrip discontinuities are considered in Chapter 7. Chapter 8 is devoted to the design of wideband impedance-matching networks. The design of RF and microwave amplifiers and oscillators is considered in Chapter 10. Cascade amplifiers, lossless feedback amplifiers, reflection amplifiers, and balanced amplifiers are considered in this chapter.

This book was improved significantly by the feedback provided by the reviewer, and I would like to acknowledge his efforts and contributions.

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