Theory of Resistive Mixers

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FOREWORD

This is the sixty-fourth volume in the M.I.T. Research Monograph Series published by the M.I.T. Press. The objective of this series is to contribute to the professional literature a number of significant pieces of research, larger in scope than journal articles but normally less ambitious than finished books. We believe that such studies deserve a wider circulation than can be accomplished by informal channels, and we hope that this form of publication will make them readily accessible to research organizations, libraries, and independent workers.

Howard W. Johnson

PUBLISHER'S FOREWORD

The aim of this format is to close the time gap between the preparation of a monographic work and its publication in book form. A large number of significant though specialized manuscripts make the transition to formal publication either after a considerable delay or not at all. The time and expense of detailed text editing and composition in print may act to prevent publication or so to delay it that currency of content is affected.

The text of this book has been photographed directly from the author's typescript. It is edited to a satisfactory level of completeness and comprehensibility though not necessarily to the standard of consistency of minor editorial detail present in typeset books issued under our imprint. A detailed table of contents is included and also an index.

The appendices are included on COSATI-standard microfiche and enclosed in an envelope at the back of the book.

The MIT Press

PREFACE

This research monograph deals with the theoretical aspects of mixers and frequency converters employing purely resistive nonlinear devices. The effects of parasitic reactances, which are bound to exist in practice, are neglected. It is the belief of the author that this is justified because today's semiconductor technology is capable of producing mixer diodes which exhibit almost purely resistive characteristics even at microwave frequencies. The need for new methods which make full use of the capabilities of these diodes are continuously on the rise. This book is an attempt to satisfy this need by finding fundamental limits on the performance of mixers and indicating the conditions necessary for their fulfillment.

It is hoped that the book will be useful to three classes of people; the student, the researcher and the design engineer. For the student, a large part of the available theory and principles of operation of mixers and frequency converters are given. For the researcher, the book adds new concepts to the theory of mixers, provides the answer to some fundamental questions and perhaps more important, it confronts the reader with more unanswered questions than those it answered. Finally, for the design engineer who is not satisfied with the performance of classic mixer circuits, the book shows the way to improved circuits and compares them to their classic counterparts.

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Finally, the author wishes to express his gratitude to the government of the United Arab Republic for providing the opportunity for him to pursue the study and research which lead to this book.

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* The Appendices for this volume, pp. 173-271, will be found on microfiche at the back of the book.

CHAPTER 1

INTRODUCTION

"Frequency converters" are used in communication receivers and transmitters, radars, radio and radar astronomy, control systems and many other applications. The frequency converter consists of a "local oscillator" or "pump" and a network containing one or more nonlinear devices and means to couple the local oscillator and the input and output signals. This network is called a "mixer". Inside the mixer the input signal, which is simply called the "signal", and the local oscillator output are "mixed" together in the nonlinear device to produce, among other frequencies, the required output frequency which is separated by filtering. The object is to achieve this with the least possible conversion loss, noise and nonlinear distortion. In hetrodyne receivers, and many other applications, the output signal is called the "intermediate frequency" (i-f). This frequency is usually the difference between the signal and local oscillator frequencies, and in most applications it is much smaller than all the other frequencies involved in the mixer.

The nonlinear device can be a resistance, a reactance or, usually, a combination of both. Traditionally, if the basic mixing process is accomplished by a nonlinear resistance, which might include some parasitic reactances, the network is simply referred to as a mixer. On the other hand if the mixing is basically accomplished by a nonlinear reactance, possibly containing resistive parasitics, the network is called a "parametric" frequency changer, although generally speaking it is still a mixer.

It is well known that a parametric up converter can produce a power gain which is equal to the ratio between the output and input frequencies;** moreover it is unconditionally stable. This makes parametric up converters very attractive in practice. On the other hand, a parametric down converter is not desirable since, although capable of producing gain, it is potentially unstable. Other examples of mixers having conversion gain are those employing negative resistance devices, such as tunnel diodes.*** However, they too have considerable stability problems. For these reasons, down converters are almost always mixers employing essentially nonlinear positive resistances. This is the type of mixer which will be dealt with throughout this book. However, all our results will be applicable to, or can be slightly modified to include up converters; and some of our results can be applied to negative resistance mixers.

** See for example Manley and Rowe (I) or Penfield and Rafuse (I).

*** See for example Chang, Heilmeier and Prager (I); Kim (I); or Pucel (I).

As suggested from the title, the book will only be dealing with purely resistive mixers having ideal selective filters. The effect of parasitic reactances, which are bound to exist with any resistive device, will be neglected. It is the belief of the author that this theoretical work is needed and that it is justified with the aforementioned idealizations, even for mixers operating in the microwave frequency region, for the following reasons:

i) Today's semiconductor technology is capable of producing mixer diodes, such as Schottky-barrier diodes,** which exhibit almost purely resistive characteristics even at microwave frequencies.

ii) The mixer imbedding networks which are built at present, together with their methods of pumping, and not the diodes and their parasitic reactances, are responsible for the greatest part of deterioration of their performances.

iii) The treatment of mixers employing purely resistive diodes, although complex enough and contains many unresolved problems as will be seen from this thesis, is considerably simpler than a treatment involving the diode parasitics. This will help us to gain a better understanding of what constitutes

** These are metal-semiconductor junction diodes where current conduction is carried out almost entirely by majority carriers. See for example Sze (I, Chapter 8) for an excellent theoretical treatment.

a good mixer and to establish fundamental limits on its performance.

In Chapter 2, the methods of analysis of different mixers employing linear periodically time-varying resistances are presented. A logical classification system based on the terminations offered to the undesired out-of-band frequencies for the different mixers is given. The system employs names based on the types of network matrices, such as Z-, Y-, H- and G-matrices, which have to be used for the analysis. The analysis given to each mixer is limited to deducing the matrix equation relating the input and output voltages and currents from the resistance waveforms. To find the complete mixer performance one should use Appendix 1, where a complete analysis is given for conversion loss, stability and passivity of two-port networks based on generalized matrix representations. One of the new results in this appendix is the problem of sensitivity of the mixer performance to source impedance variations. Also, Appendix 2 provides the necessary equations for mixers with different image frequency terminations based on the generalized three-port matrices found in Chapter 2.

In Chapter 3, three basic questions concerning fundamental limits on the performance of resistive mixers are given. The questions involve obtaining the optimum resistance waveforms for the different mixer imbedding networks introduced in Chapter 2, and finding the optimum imbedding networks for different nonnegative resistance waveforms. The parameter to be optimized is the mixer conversion loss. The theme of Chapter 3 can be considered as a search for the world's best mixer.

In both Chapters 2 and 3, the resistance waveform is assumed to be completely arbitrary and independent of the imbedding network. In practice, however, this is not true since the resistance waveform is obtained by pumping a nonlinear device in the imbedding network; and thus it depends on the device used, the method of pumping employed and the imbedding network. This is the purpose of Chapter 4.

In Chapter 4 different mixers employing ideal exponential diodes are analyzed and compared. The analysis given for each mixer consists of two main parts: large-signal and small-signal analyses. The first part includes the calculation of the pumped resistance waveform, the pump power, the resistance offered to the pump and the d-c bias conditions. In the second part of the analysis, the optimum values of the conversion loss and source and output resistance are given for different image frequency terminations. In each case asymptotic approximations are used to obtain simple formulas which are accurate for strongly driven mixers.