Chapter 16

HEMT for RF Circuits

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ABSTRACT

In this chapter, III-V compound semiconductors MESFET, HBT, and HEMT are described, including papers which report major achievements of the HEMT technologies in the fields of microwave, millimeter-wave, and digital Integrated Circuits (ICs). The important aspects of device physics, small-signal equivalent circuits for GaAs, and GaN-based HEMT are discussed. The authors present a comparative analysis of different analytical modeling techniques and show that the differences reflect the physical and technology differences of the tested microwave transistors. The purpose of this chapter is to facilitate the choice of the most appropriate strategy for each particular case. For that, the authors present a brief but thorough comparative study of analytical techniques developed for modeling different types of advanced microwave transistors: GaAs HEMTs, GaN HEMTs. The chapter shows that a crucial step for a successful modeling is to adapt accurately the small-signal equivalent circuit topology.

INTRODUCTION

Advances in integrated circuits technology are the key to opening and fully exploiting new consumer electronics market opportunities. This is exemplified recently by the massive expansion of the mobile communications which is fundamentally underpinned by advances in semiconductor manufacturing technologies. FET (Field Effect Transistor) at microwave frequency using the III-V compound Gallium Arsenide (GaAs) has been most exciting device to emerge from solid state microwave community over past three decades. FET with new materials (GaN, InP, SiC) has now become an established item in microwave systems of today for high power, temperature and frequency applications. A Monolithic Microwave Integrated Circuit (MMIC) is a microwave circuit in which the active and passive components are fabricated on the same semiconductor substrate. The frequency of operation can range from 1 GHz to 1 THz, and a number of different device technologies and circuit approaches can be used.

With increasing demand of high power level and operating frequency of RF and microwave...
circuits in modern wireless systems, today’s high frequency power devices mostly based on Gallium Arsenide (GaAs) will soon come to their power limits. To still satisfy the requirements of future wireless systems, numbers of research activities in the field of wide-bandgap semiconductor materials are initiated. The different microwave materials of interest are Indium phosphide (InP), Silicon carbide (SiC) and Gallium Nitride (GaN) of this category with a great potential for high power, temperature and frequency applications. Due to high power densities of GaN and SiC (about 10 times as high as GaAs’s), these semiconductor materials are outstanding for power devices.

At a comparable power level and the frequency range of mobile communication applications, the material cost of SiC is much higher than GaN’s. GaN based transistors are capable of operating in wide frequency and power ranges. Their outstanding electrical and thermal properties have been demonstrated and reported in the literature (Daumiller, et.al., 1988, Shen, et.al., 2004, Weimann, et.al., 2003, Xing, et.al., 2004). Beside a high power density, the thermal conductivity of GaN is much higher than GaAs’s, so that operations at higher temperature and power levels are possible with less cooling requirements. High power MMICs with GaN based High Electron Mobility Transistors (HEMT) can be processed on low cost substrate materials e.g. Al₂O₃ or Silicon. Another substrate material for GaN based transistors is SiC which should be used only for extremely high temperature and high power applications due to its high cost. Thus, although GaAs based transistors are currently the dominating devices for high frequency applications, it is expected that they will be soon replaced by GaN based HEMTs which will establish to be the key devices for future wireless communication systems and other high frequency, temperature and power applications.

**HISTORY OF MMIC TECHNOLOGY**

III-V compound semiconductors are used for MMIC because of its suitability for both high frequency transistors and low loss passive components.

- **1962**: 24 µm: Fabrication of transistor using GaAs was first carried out by Jim Tuner.
- **1967**: 4 µm: Producing 10 dB gain at 1 GHz.
- **1971**: 1 µm: EBL Technology (Electron Beam Lithography) given high gain at 1 GHz.
- **1981**: Horn buckle & Van Tuyl presented results for direct-coupled amplifier using transistors and level shifter diodes.
- **1982**: RFW (Radio Frequency on Wafer).
- **1984**: High Power & High gain amplification techniques presented by Ayasli.
- **1988**: Small Signal Equivalent Circuit of FET for MMIC’s by Gilles, et.al.
- **1990**: Distributed amplifiers entered a new era when HEMTs become available, and the standards were redefined by the 5-100 GHz bandwidth by Majidy-Ahy.
- Currently, new materials for MMIC such as InP, GaN on SiC, Si and diamond substrate have a evolution for high power, high frequency and high temperature applications of MMIC’s.

**SILICON BASED RF MMIC**

Silicon technology has continued to evolve, to address the need of contemporary analogue and digital applications. Most recently, the development has been strongly driven to meet the requirements of the wealth of the high volume consumer electronics applications that have begun to appear in the GHz frequency range, such as RF chipsets for
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