Thermal Modeling and Memory Effects in Modern Day Transistor Technologies

The new generation of high performance RF power transistors being developed in wide bandgap technologies present some new challenges in terms of both characterization and modeling due to their exceptionally high power density and output power. Furthermore some of these devices are affected by various low-frequency dispersion processes (thermal and trapping memory effects) which impact their RF performance. In this tutorial we will review the physics of the self-heating, trapping and associated memory effects in GaN HEMTs and other RF power devices. We will also present some recent large-signal pulsed RF experimental techniques developed to characterize these effects.

We will review the three dimensional CW and transient modeling of thermal effects in layered devices including numerical methods and analytic methods such as the image method. Simpler distributed models amenable to circuit simulation for multi-finger devices will be presented. Then we will address the transient thermal response and its representation using a multiple time-constant thermal model. Evidence of thermal induced IV-knee walkout in GaN HEMTs on sapphire will be provided based on pulsed-IV pulsed RF large-signal measurements for different substrate temperatures. Finally we will present evidence of very fast thermal responses in large-signal RF excitations of GaN HEMT under pulsed drain-bias modulation.

Various trap mechanisms have also been demonstrated to be responsible for knee voltage walkout in GaN HEMTs. We will review surface states on the AlGaN top layer and deep levels in the GaN layer which are believed to be responsible for gate and drain lag effects respectively. Various models which have been reported to characterize these traps in circuit simulations will be presented. Finally to identify traps and characterize their time constants, some preliminary results from a new methodology combining deep level optical spectroscopy (DLOS) and large signal network analyzer (LSNA) RF measurements will be presented.

This tutorial will conclude with examples of the impact of memory effects at both the circuit and system levels with (1) a demonstration of the importance of thermal and non-thermal memory effects in the predistortion linearization of amplifiers and (2) with a comparison of CW and pulsed-RF loadpull results for Class B operation.