# NEURAL NETWORK BASED ELECTROTHERMAL CIRCUIT MODEL OF POWER HEMT

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**Abstract** *This paper presents large signal electrothermal circuit model of power HEMT. The model is calibrated automatically by artificial neural network (NN). Appropriate setting and properties for NN training is described. Very high accuracy of the proposed model is observed. The advantages and limitations of NN for circuit electrothermal modeling are discussed.*

**Keywords** neural network, electrothermal circuit model, power HEMT

## 1. INTRODUCTION

Simulation and modeling represent powerful tools for analysis, characterization and optimization of a new structures, devices and circuits. Simulation can define critical areas and improve device and circuit performance. The circuit simulations become more substantial with the ongoing development of complex integrated circuits (IC). Circuit simulations are used routinely in the design and optimization of IC. However, well calibrated models for accurate simulation results are required. Many recently published papers describe very accurate transistor models [1-3]. However, their accuracy is mostly proportional to the number of input parameters and complexity of input dependencies.

This paper introduces artificial neural network (NN) for calibration of electrothermal circuit model of power HEMT. NN technique shows promising results in device modeling. NN approach provides capability to approximate nonlinear electrothermal behavior with very high accuracy. The advantage of the proposed method is in the simplicity to build and calibrate electrothermal circuit models of power devices.

## 2. ARTIFICIAL NEURAL NETWORK

The artificial neural network is a powerful tool for predictive simulation and modeling. NN is capable to learn a certain relation between the input and output parameters as a function fitting. NN is a network of artificial neurons connected by artificial synapses modeled by weights expressing the contribution of the respective inputs to the output. Input artificial neurons receive input values described by input variables and output neuron describes output variable. Artificial sigmoid neurons are represented by activation function which controls the amplitude of the output as a nonlinearly weighted function of inputs. Artificial synapses are modeled as weights determining existing or inhibiting connection between neurons. These weights are determined during the training process of the NN [4-6].

## 3. MODEL DESCRIPTION

The device under investigation is a power HEMT fabricated with AlGaN/GaN heterostructure grown on SiC substrate. Fig. 1 depicts the proposed electrothermal model of HEMT. The model consists of electrical and thermal parts.

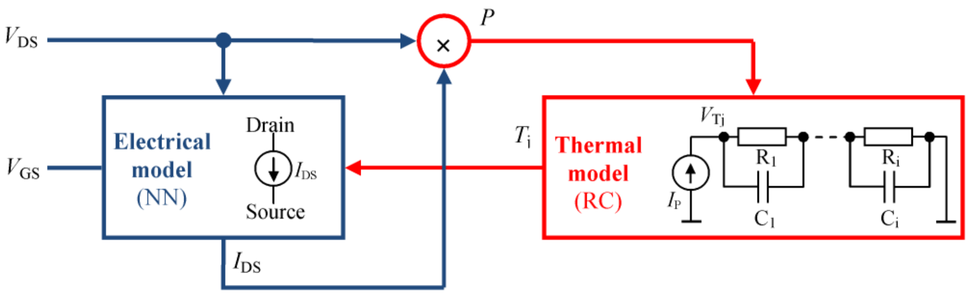


Fig. 1 Circuit diagram of the power HEMT electrothermal model.

The electrical part is modeled by drain-source current source $I_{DS}$. The model of the $I_{DS}$ is created by NN in MATLAB. The $I_{DS}$ is described as a function of drain-source voltage $V_{DS}$, gate-source voltage $V_{GS}$, and temperature $T_j$:

$$I_{DS} = f\left(V_{DS}, V_{GS}, T_j\right). \tag{1}$$

The network for $I_{DS}$ source consists of three inputs and one output. Two hidden layers with ten and three neurons are used for high accuracy. The so-called Bayesian regularization function with a maximum number of 1000 epochs and a minimum performance gradient of $1\times10^{-15}$ is set to network training. The training of the proposed NN was performed using the experimental data to obtain set of the weights. The experimental data were obtained from 2-D FEM electrothermal simulation calibrated with I-V-T measurement and infrared imaging camera of the analyzed HEMT.

The thermal part of the proposed model is based on electrical *RC* network. Foster-type electrical *RC* network represents the thermal impedance of the HEMT. The current sources $I_P$ proportional to the transistor dissipated power $P$ is fed into the thermal equivalent network. The $V_{Tj}$ voltage represents the temperature $T_j$ of the HEMT. The *RC* elements are extracted automatically by MATLAB from thermal impedance curves obtained by 3-D FEM thermal simulations calibrated with infrared imaging measurement. Due to a strong temperature dependence of the thermal conductivity of the used materials, the designed thermal network consists of temperature dependent resistors and capacitors. The resistors and capacitors are driven according to thermal impedances at different temperatures.

## 4. SIMULATION RESULTS AND VALIDATION

Fig. 2 shows the experimental data and simulated results of output and transfer characteristics of the power HEMT at different ambient temperature $T_{amb}$. The error of the NN model is calculated as an average of deviation for all experimental data and simulated results. The average error of simulated $I_{DS}$ is about 0.24 %.

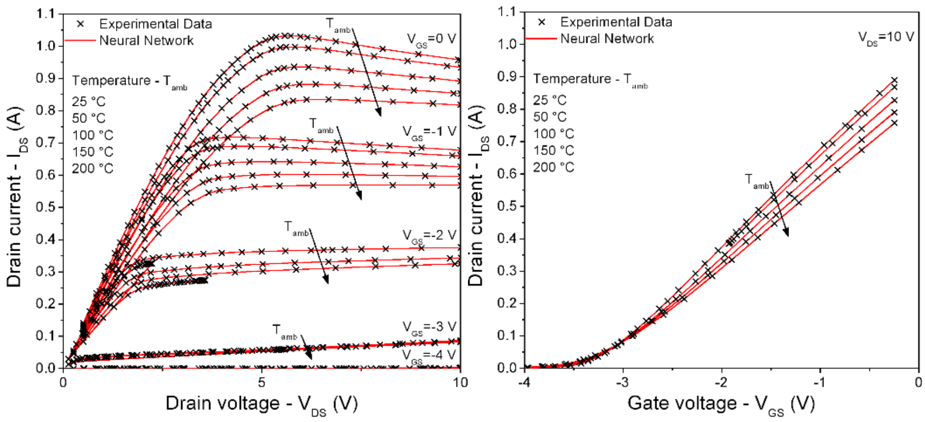


Fig. 2 Experimental data and simulated results of output and transfer characteristics of the power HEMT at different ambient temperature $T_j$.

Comparison of 3-D FEM and *RC* network simulated thermal impedances of the power HEMT at different temperature is shown in Fig. 3. The average deviation of equivalent *RC* network thermal impedances is about 1.15 %. Very good agreement between simulations and experimental data confirms the validity of the proposed electrothermal circuit model of power HEMT and methodology for model calibration.

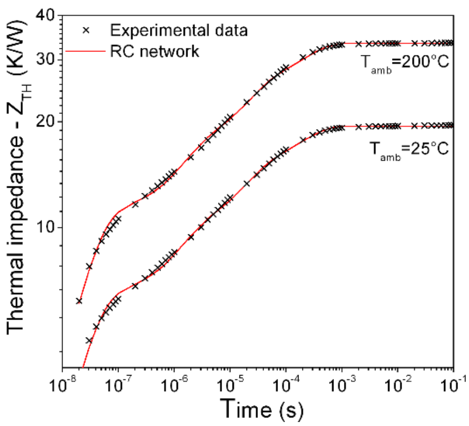


Fig. 3 Thermal impedance of HEMT at different temperatures.

## 5. CONCLUSION

Electrothermal circuit model of power HEMT has been presented. The model has been proposed and calibrated by neural network. Appropriate setting and advantages of NN for circuit modeling have been discussed. Very high accuracy of the proposed NN models has been observed. Another advantage of the proposed NN is relatively simple creation and automation of the calibration process of circuit models for complex power devices. Very good agreement between the experimental data and simulations confirms the validity of the proposed model and methodology for electrothermal circuit models preparation and calibration using NN.

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