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# Consensual noise modeling of a microwave transistor

*By*

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***Abstract:***

In this work, a consensual approach is developed and applied to the noise modeling of microwave transistors. In the proposed method, multiple individual models generated by an expert system ensemble are combined by a consensus rule that results in a consistent and improved generalization outputting with the highest possible reliability and accuracy. Here the expert system ensemble is basically constructed by the competitor and diverse regressors which in our case are Back-Propagation (BP) Artificial Neural Network (ANN), Support Vector Regression Machine (SVRM), k-Nearest Neighbor (k-NN) and Least Squares (LS) algorithms that perform generalization independently from each other.

***Keywords:***

Consensual modeling, artificial neural networks, support vector regression, least squares and k-nearest neighbor algorithm

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## 1. Introduction:

In this work, we emphasize reliability of the “modeling” as well as efficiency in its development process and accuracy in its generalization performance. Thus, with this motivation, we work out a consensual modeling of expert regressor systems for microwave transistors. In literature, significant works on consensual approach for classification/regression can be ordered as follows: Classification of remotely sensed multispectral images using hierarchical neural networks [1]; classification of drug/nondrug compounds for drug design [2-3]; a consensus Least Squares Support Vector Regression (LS-SVR) for analysis of near-infrared spectra of plant samples [4].
In this work, novel competitor and diverse regressors which are Back-Propagation (BP) Artificial Neural Network (ANN), Support Vector Regression Machine (SVRM), *k*-Nearest Neighbor (*k*-NN) and Least Squares (LS) algorithms are employed to build nonlinear mappings between discrete independent and dependent variables of the microwave devices. Then, the independent multiple nonlinear mappings satisfying the acceptance criteria are combined by a consensus rule that results in a consistent and improved generalization outputting with the highest possible reliability and accuracy.
We applied the consensual modeling technique to obtain the noise parameters of a microwave transistor. Particularly, in this worked example, it can be observed that the resulted consensus model for each noise parameter will effectively identify and encode more aspects of the nonlinear relationship between the independent and dependent variables than will a single model due to diversity in generalization process of each member of the ensemble.
The paper is organized in five sections: Next section is devoted to the theory and algorithms of the consensual modeling; then consensual modeling for the noise parameters of microwave transistor take place in the third section. The conclusions finally end the paper in the fourth section.

## 2. Theory and algorithm:

***Theory of Consensual Modeling***

In consensual modeling, the multiple nonlinear mappings resulted from each member of the competitor and diverse regressor ensemble, are combined by a consensus rule. Here, the basic idea of consensual regression is that these multiple nonlinear mappings will effectively identify and encode more aspects of the relationship between discrete input $\vec{x}$ and output $y$ variables than will a single nonlinear mapping. Thus, theoretically the error of a consensus model $e(\vec{x})$ can be combined as the two ingredients as follows [4-5]:

$$e(\vec{x}) = \varepsilon(\vec{x}) - a(\vec{x}) \tag{1.1}$$

where $\varepsilon(\vec{x})$ is the average error across all the member models, while $a(\vec{x})$ is the variance of the member models respect to the results of the consensus model:

$$\varepsilon(\vec{x}) = \frac{1}{N_m}\sum_{i=1}^{N_m}(y-\hat{y}_i)^2 \qquad (1.2)$$

$$a(\vec{x}) = \frac{1}{N_m}\sum_{i=1}^{N_m}(\hat{y}_i-\hat{y})^2 \qquad (1.3)$$

where $N_m$ is number of the member models, $\vec{x}$ is the vector of independent input variables, $y$ is the dependent variable, $\hat{y}_i$ is the prediction result of the *i*th member model, while $\hat{y}$ is the prediction of the consensus model, which is obtained by applying the consensus rules to the member models satisfying the acceptance criteria. Here, these consensus rules may be in the form of:

- the average of the prediction results: $\hat{y} = \frac{1}{N_m}\sum_{i=1}^{N_m}\hat{y}_i$ (2.1)
- the minimum of the prediction results: $\hat{y}$=min ( $\hat{y}_i$ ) (2.2)
- the maximum of the prediction results: $\hat{y}$=max( $\hat{y}_i$ ) (2.3)
- the median of the prediction results: $\hat{y}$=median( $\hat{y}_i$ ) (2.4)

Clearly, it can be seen from Eq. (1.1) that the error of consensus model $e(\vec{x})$ can be minimized by a tradeoff between $\varepsilon(\vec{x})$ and $a(\vec{x})$. The former is a measure of predictive quality of individual member models and the later is a measure of diversity of the member models as given by Eqs.(1.2) and (1.3), respectively. Therefore, the consensus modeling can be well performed only if the combined regressors are simultaneously accurate and diverse enough, which requires an adequate tradeoff between those two conflicting conditions [6].

***Consensual Regression of the Expert Systems***

The block diagrams of training and final model of consensual modeling of the expert systems employed in our work is given in Fig. 1a and b, respectively. In this consensual modeling, a member model is selected by a criterion of prediction accuracy and all the accepted models are adopted to predict the output $y$ dependent on the input vector $\vec{x}$. The accepting criterion for the membership to the expert system is defined by the prediction accuracy based on the mean relative error between the target and the prediction values of the assessing data set as follows:

$$Accuracy = 1 - \frac{\sum_{i=1}^{n}|y_i - \hat{y}_i|}{\sum_{i=1}^{n} y_i} \qquad (3)$$

where $\hat{y}_i$ and $y_i$ are the predicted and target values respectively, of the ith data sample for $i$=1,..,n. When the prediction accuracy is higher than a certain threshold, the constructed model will be accepted as a member model of the consensus method. The final prediction result is obtained from the consensus rule chosen among the rules given in the previous subsection by the decision mechanism (Fig.1a).

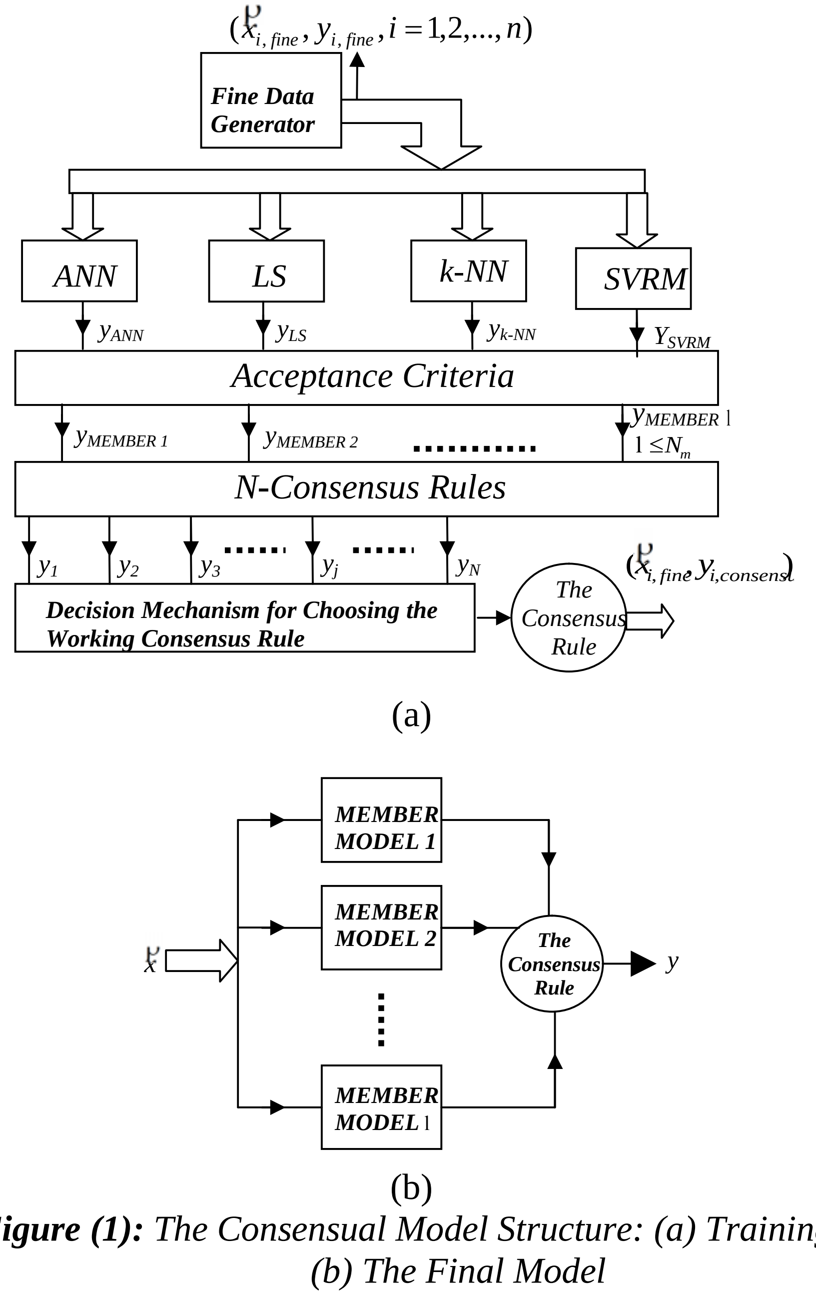


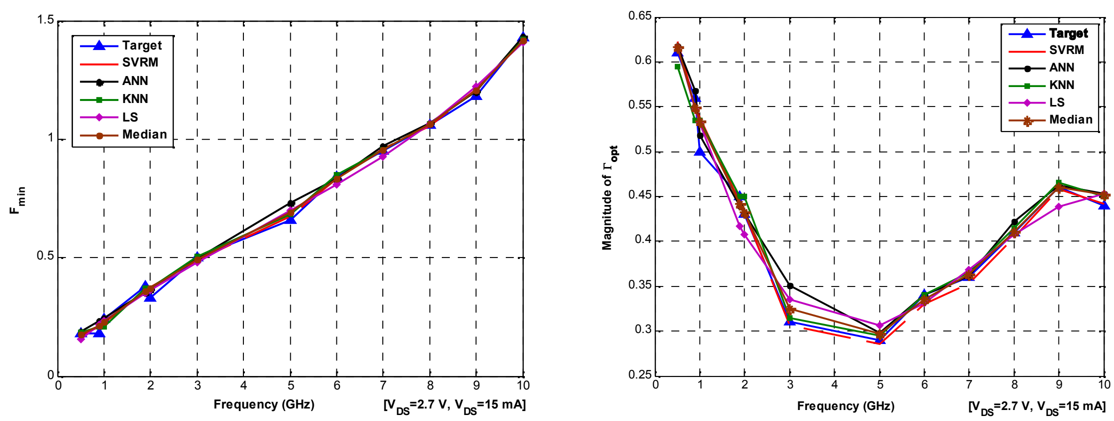

***Figure (1):*** *The Consensual Model Structure: (a) Training Phase, (b) The Final Model*

Application of the consensual modeling of the four expert systems to the noise modeling of a microwave transistor will be given in the following section.

## 3. Typical worked example: Consensual noise modeling of a microwave transistor

As an application example for consensual modeling of an active device, ATF-551M4 is chosen as a microwave transistor and its noise (N-) parameters which are the minimum noise figure $F_{min}$, the source termination $|\Gamma_{opt}|\angle\varphi_{opt}$ for the noise matching and the noise resistance $R_n$ are modeled at $V_{DS}$ =2.7V and $I_{DS}$=15mA within the frequency range of 0.5 – 10 GHz. In this worked example, fine data is provided from the manufacturer's data sheets of ATF-551M4. As performed in [11], altogether 72 noise data samples within the frequency range of 0.5 GHz to 10 GHz at $I_{DS}$ =10mA, 15mA and 20mA of $V_{DS}$ =2V, 3V are utilized for training of the ANN and SVRM, then 36 noise parameters are predicted within the same frequency band at $I_{DS}$ = 10mA, 15mA and 20mA of the $V_{DS}$ =2.7V. Fig.2 a, b give respectively the variations of the noise parameters $F_{min}$, $|\Gamma_{opt}|$ obtained by the members of the expert system ensemble for the ATF551M4. Furthermore, angle modeling of $\Gamma_{opt}$ resulted from the consensus strategies for the ATF551M4 are compared with the target in Fig. 3.

In this work, decision mechanism for choosing the working rule of the consensus is based upon the two criteria: (1) Total accuracies resulted from the consensus rules; (2) Scatter variations between the predicted and target data and their evaluating characteristics parameters. The consensus strategy in the form of "Median of the prediction results: $\hat{y}$=median($\hat{y}_i$)" in (2.4) has finally been decided as the working rule to construct "consensus" between the member models of the ensemble. Fig.4 a, b, c, d give scatter plots of the member models and the resulted scatter plot of the working consensus rule is given in Fig.5, where reason for why the median is chosen as a working consensus rule can be observed easily. In this scatter plots, R and SD stand for correlation coefficient and standart deviation, respectively.




( a ) (b)

***Figure (2):*** *Noise parameters obtained by the members of the expert system ensemble for the ATF551M4: (a) $F_{min}$; (b) $|\Gamma_{opt}|$*

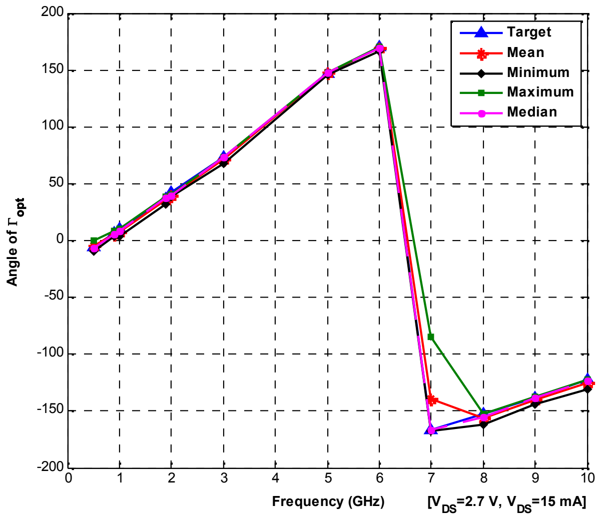
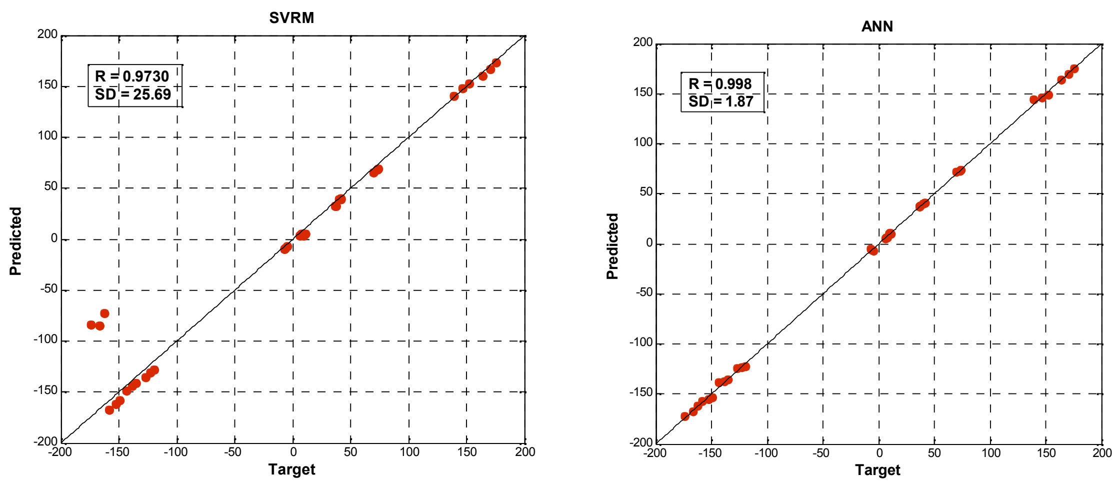
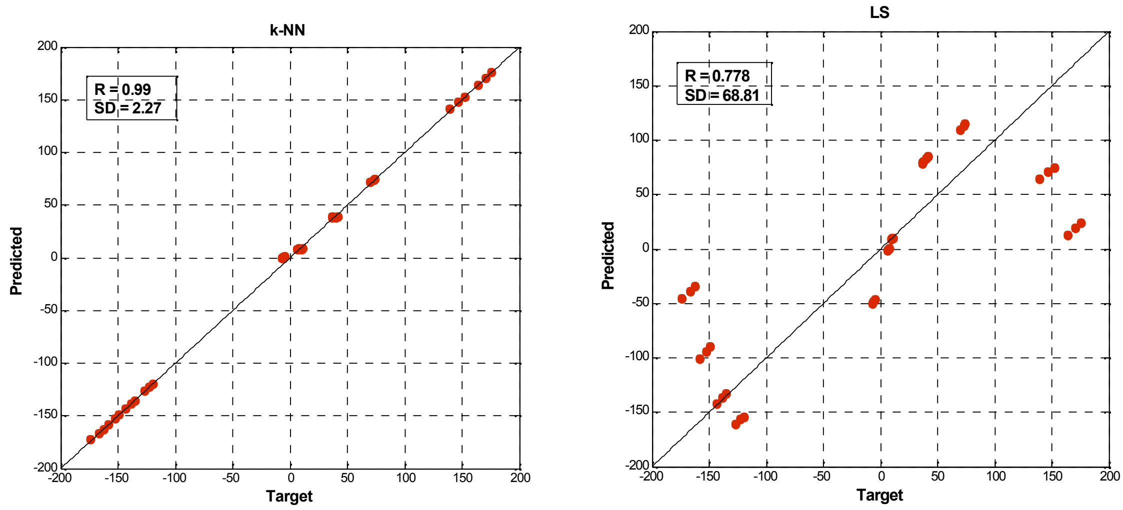



***Figure (3):*** *Angle of* $\Gamma_{opt}$ *resulted from the consensus strategies for the ATF551M4*




(a) (b)




(c) (d)

***Figure (4):*** *Scatter variations between the predicted and target data for the noise modeling of the ATF551M4 using (a) SVRM; (b) ANN; (c)k-NN; (d) LS*

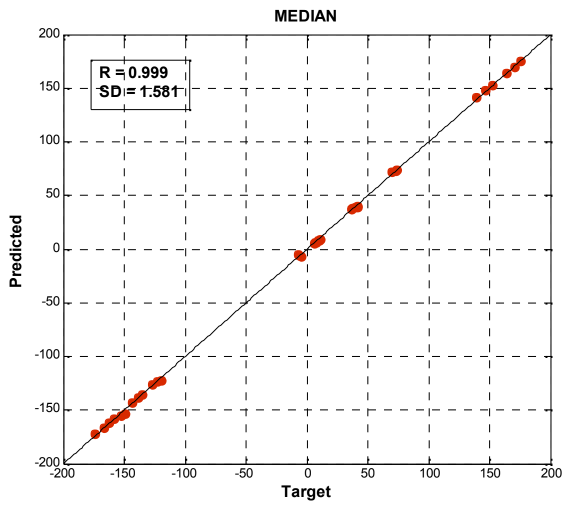



***Figure (5):*** *Scatter variations between the predicted and target data for the noise modeling of the ATF551M4 using Median consensus strategy*

## 4. Conclusions:

This work may be considered as a significant development in microwave device modeling theory, since it satisfies all the main requirements of "the get-it- right-the first-time fabrication", by constructing the device models with the highest possible reliability and accuracy in a very efficient manner. The properties of the reliability, accuracy and efficiency of the consensual modeling are verified typically for a microwave device: An active device modeling which is noise modeling of a microwave transistor. This modeling approach is expected to find many applications in the microwave technique, especially in reliable and accurate generalization of the finite discrete data obtained from either Electromagnetic Simulators or measurements.

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