ANN Based Modeling of Active Components

Small Signal Component Models: direct modeling of component external behaviors

NN inputs:

Physical / geometrical parameters and/or electrical parameters

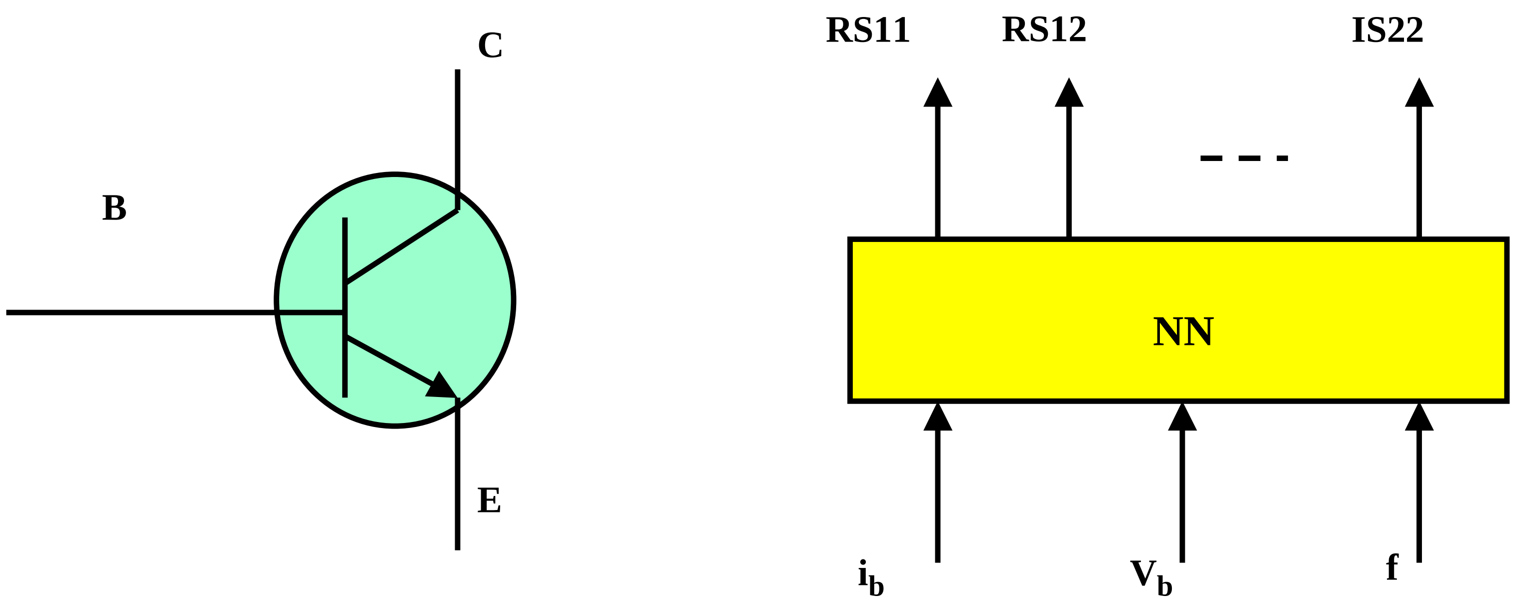
NN outputs:

$Y_{2\times2}$ -- for 2-port components (explicitly compatible to nodal analysis of circuits)

$S_{2\times2}$-- for 2-port components (popular form for high frequency circuit design)

Z or H

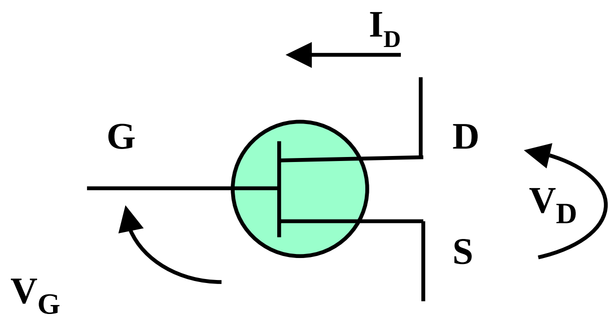
Example – HBT Modeling by NN (Devabhaktuni, Xi and Zhang, 1998)

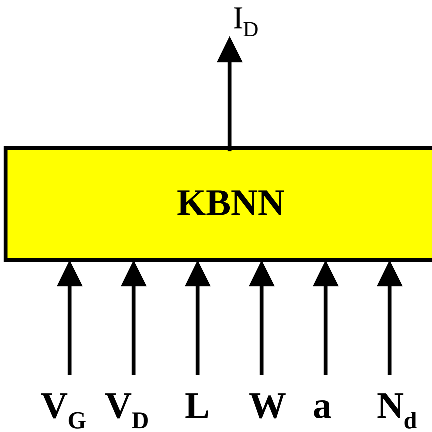


Training data obtained from S-parameter measurements

DC Model: (Wang & Zhang, 1997)

Direct modeling of component external behaviors
Example – physics based FET and its NN model:





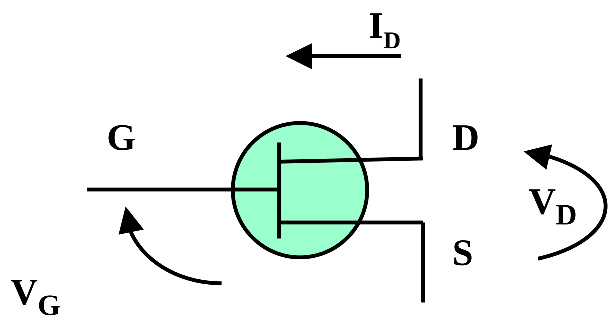
where **L – Gate length**
W – Gate width
a – Channel thickness
N_d – Doping density

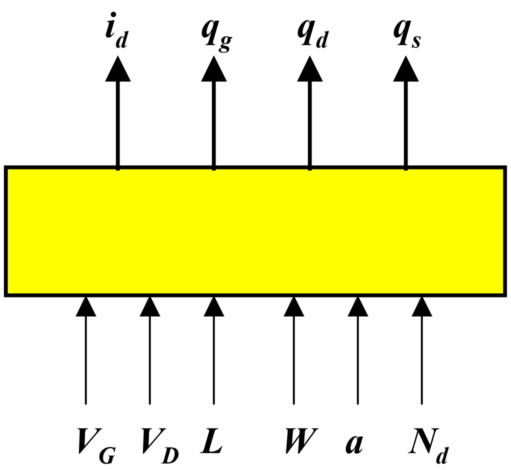
Training data obtained from OSA90 simulation with Khatibzadeh & Trew model

Large-Signal Model (Zabaab, Zhang & Nakhla, 1994):

Direct modeling of component external behaviors

Example -- same active component FET

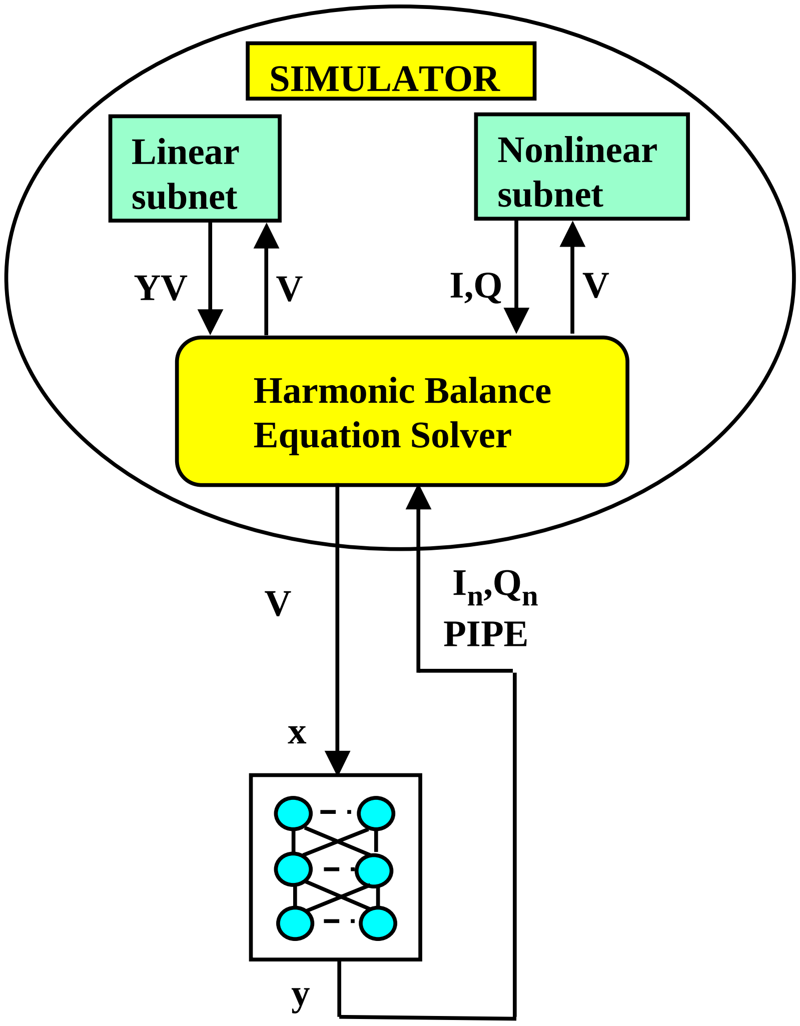




This form is explicitly compatible to harmonic balance analysis of nonlinear circuits

Training data obtained from OSA90 simulation with Khatibzadeh & Trew model

Implementation of neural network models into circuit simulator



Time-Varying Volterra Kernel Based Model (Harkouss et al., 1998):

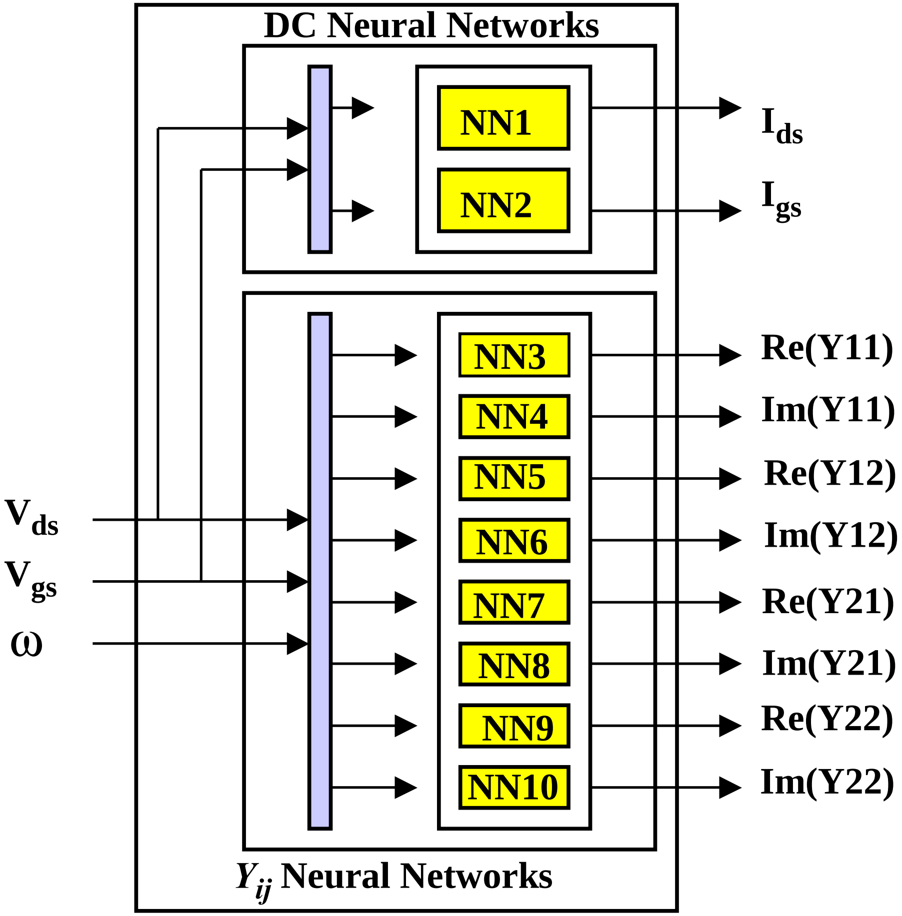
- **Time-varying Volterra series**

$$i_i(t) = I_{i_0}\{v_1(t),\cdots,v_n(t)\} + \sum_{j=1}^{n}\sum_{p=-P}^{P} Y_{ij}\{v_1(t),\cdots,v_n(t),\omega_p\} V_{jp} e^{j\omega_p t}$$

$$i = 1,\cdots n$$

- **The global neural network architecture modeling the device is composed of 10 neural networks (DC currents and 4 Volterra admittance), which is shown in next page**
- **Training data is obtained from measurements. DC term is defined by DC device measurements, and the time varying kernel is directly related to the measured device bias dependent Y parameters, on all the frequency range**

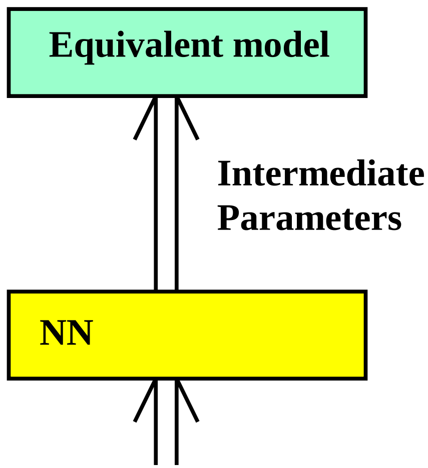
Time-Varying Volterra Kernel Based Model



DC/Small/Large-Signal Component Model: indirect modeling through a known equivalent circuit model

Linear or nonlinear, small signal or large signal, static or dynamic

General neural model:



Original model inputs

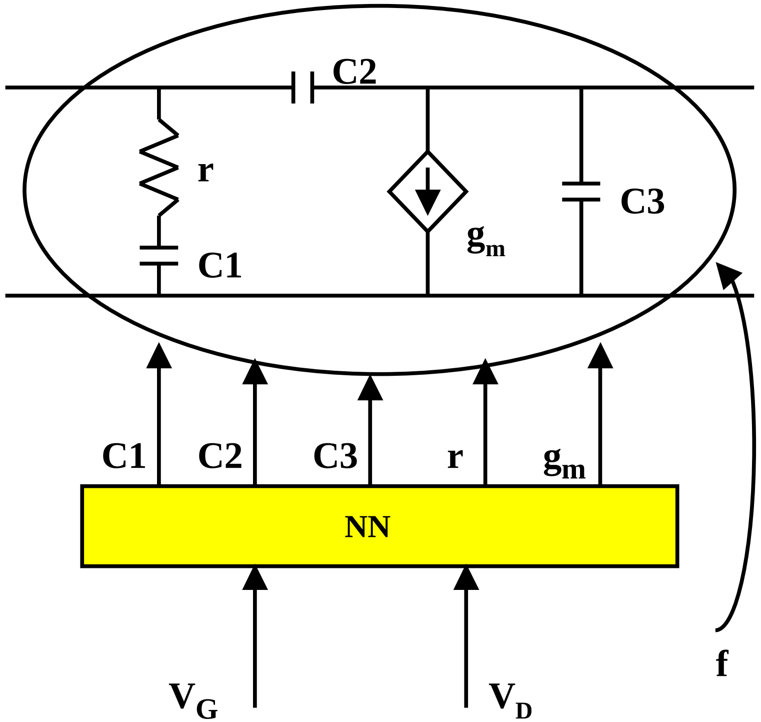
Typical: equivalent circuit model with known topology but unknown values of parameters

Typical: parameters in equivalent circuit model

Neural Networks

Typical: physical parameters

Example -- Small Signal FET



NN Training Data:

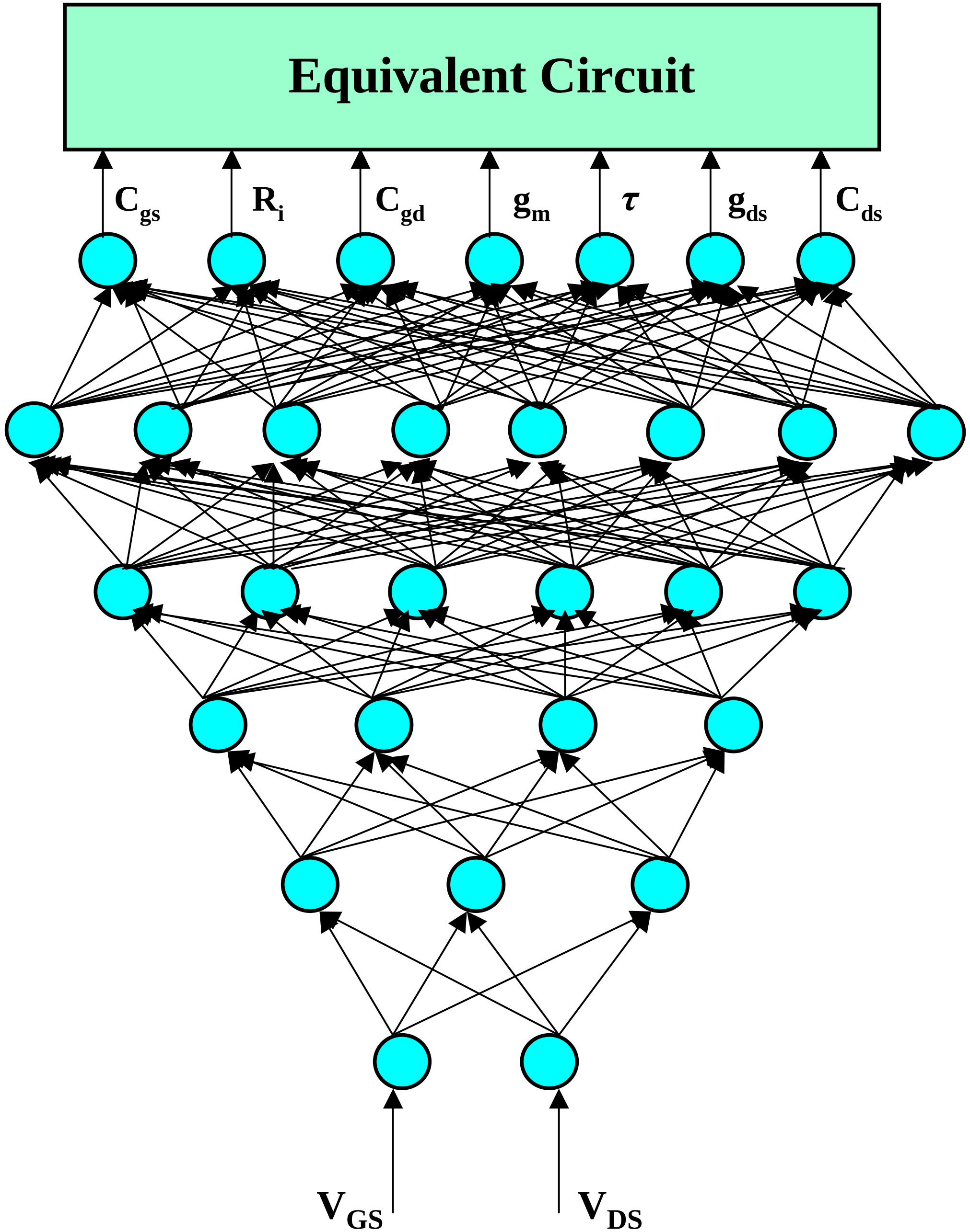
Model parameter extraction using s-parameter measurement to find *C1, C2, C3, r,* g_m from given biases (V_G , V_D)

Example – NN Modeling of HEMT (Shirakawa et al., 1997):

- **Characterize large-signal behavior with a conventional small-signal equivalent-circuit analysis, compatible to standard harmonic balance simulators**

- **Neural network models the bias-dependent intrinsic elements (** $C_{gs}, R_i, C_{gd}, g_m, \tau, g_{ds}$ **and** C_{ds} **) with inputs of** V_{gs} **and** V_{ds}

- **Five layer perceptrons of total 28 neurons**



- The V_{GS} *and* V_{DS} dependent intrinsic elements data are extracted from the S-parameter measurements performed at various bias settings

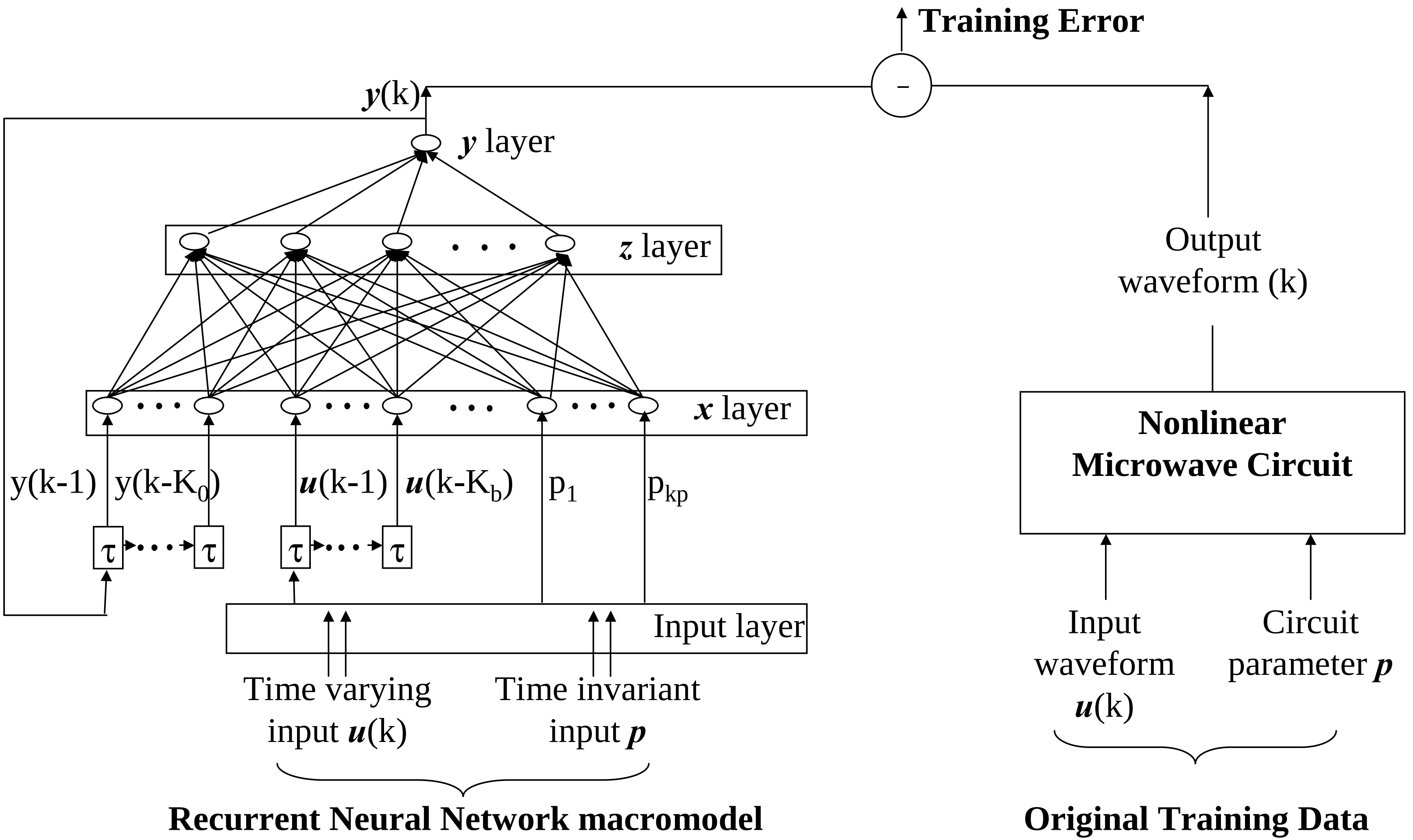
Macromodel of Nonlinear Circuits Based On Recurrent Neural Networks (RNN) (Fang, Yagoub, Wang, and Zhang, 2000)

Input-output waveforms of nonlinear circuit are used as training data

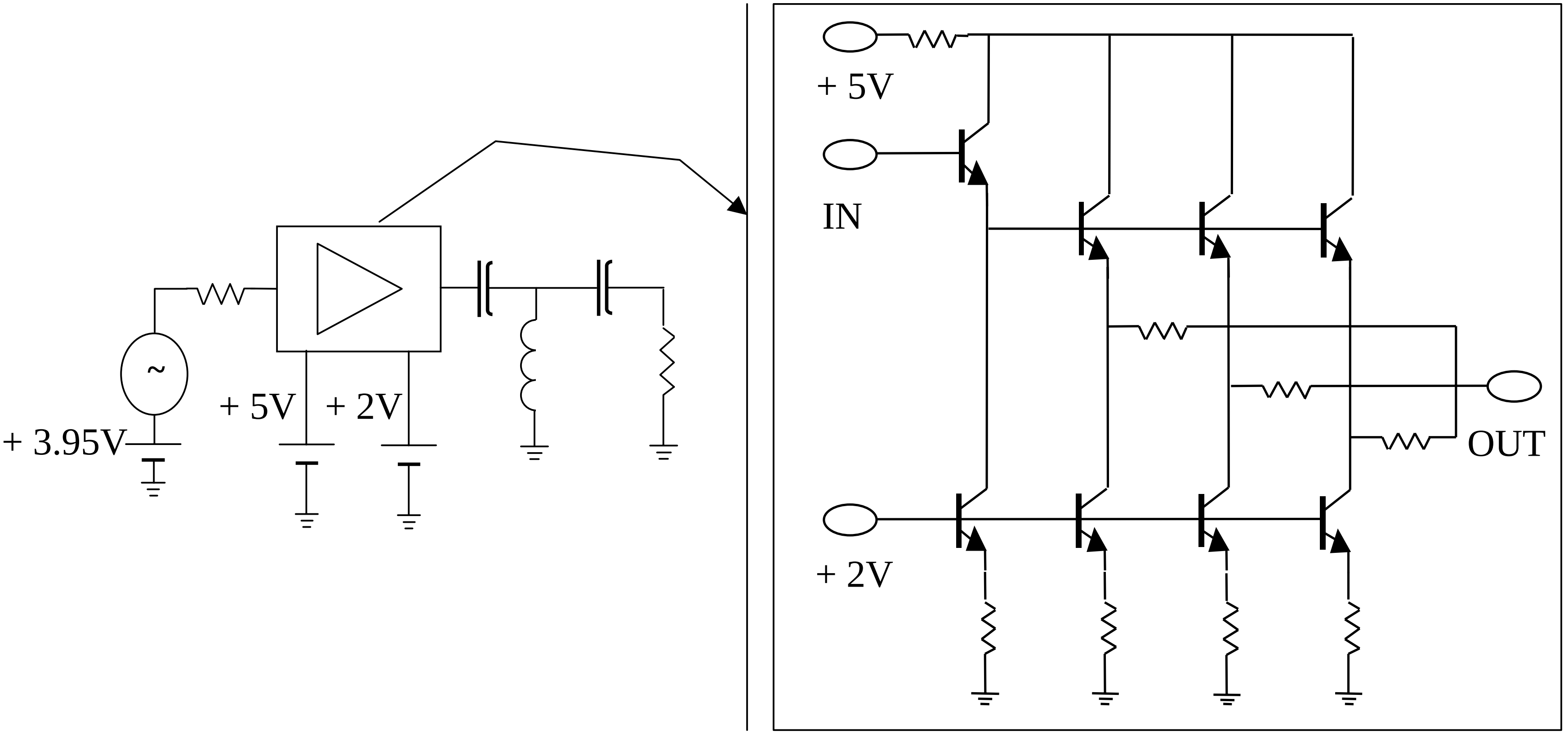
Additional circuit parameters can also be added as neural network inputs

Macromodel represents dynamic behavior of nonlinear circuits

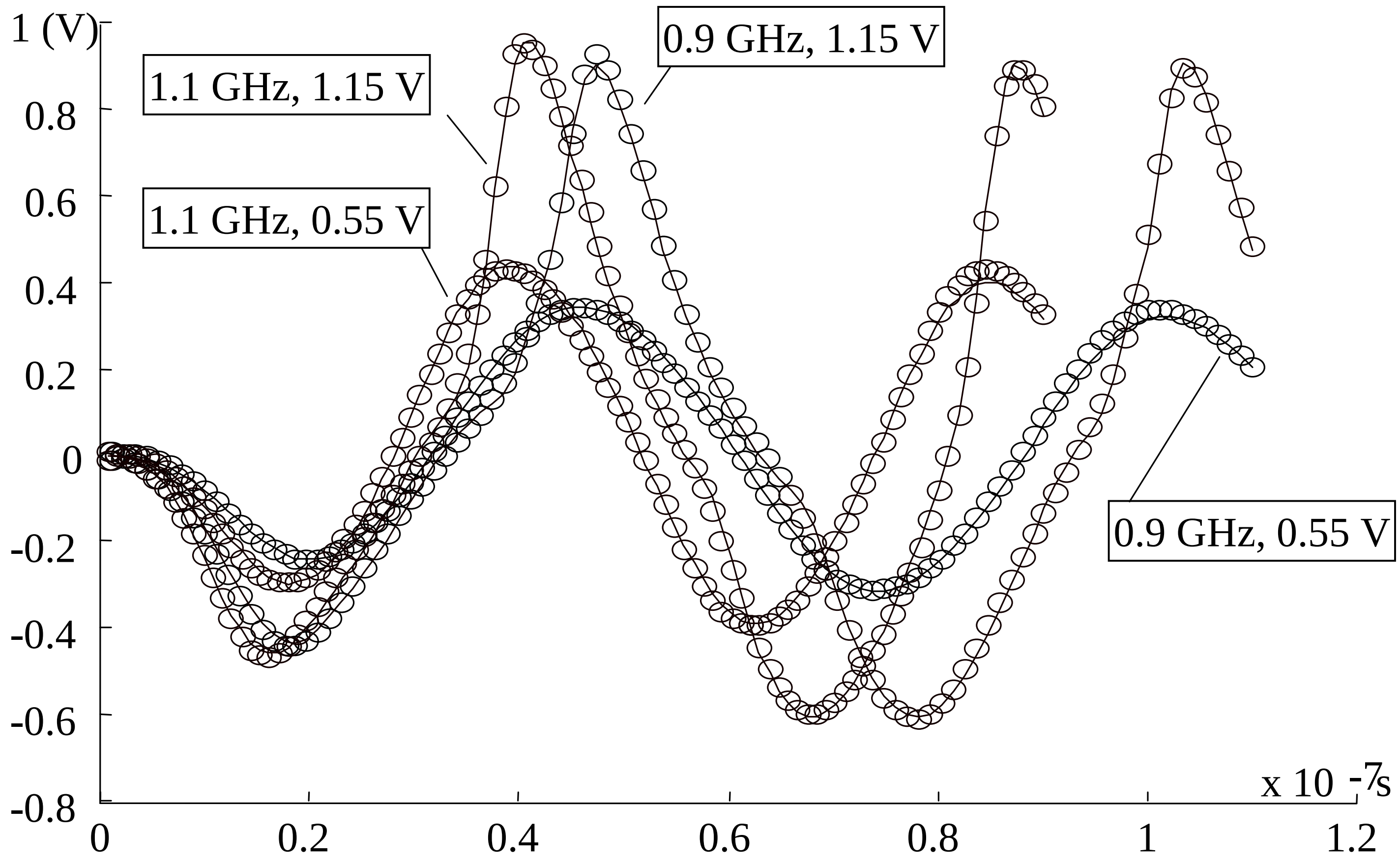
The Nonlinear Macromodeling Structure



Power amplifier circuit to be represented by RNN macromodel



Comparison between original amplifier waveform (o) and that from a trained RNN macromodel with 3 buffers (-). (freq. = 0.9, 1.1 GHz, Amplitude = 0.55, 1.15V)



Amplifier: Recurrent training and testing vs. different number of hidden neurons in *z* layer

Number of Hidden Neurons in *z* layer	Recurrent Training Error (3 buffers)	Recurrent Testing Error (3 buffers)
30	1.35e-2	1.43e-2
40	1.08e-2	1.11e-2
50	1.06e-2	1.04e-2
60	1.12e-2	1.19e-2

Amplifier: Comparison of recurrent model against different numbers of buffers

No. of buffers (K_0)	Recurrent Training Error	Recurrent Testing Error
1	3.11e-2	3.00e-2
2	1.81e-2	1.83e-2
3	1.06e-2	1.04e-2
4	9.10e-3	9.33e-3

Discussion:

Neural Models in general:

Allow the design/adjustment of component physical parameters and tolerance analysis of physical parameter variations.

Direct modeling of external behaviors:

- **Overall model could include all practical effects, non-ideal effects, new semiconductor effects not covered in available commercial models**
- **Easier to develop even without theory / experience / knowledge of the component when using measured data to train a NN**
- **With no or much less assumptions than circuit based models**

Indirect modeling through a equivalent circuit model:

- **Easily compatible with circuit simulator, including time-domain and frequency-domain simulations**
- **Possible with dynamic models**
- **Limited by equivalent circuit model assumptions**