Automatic Impedance Matching with a Neural Network

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***Abstract*—A neural network is developed for the stub-tuning process. The determination of a double-stub solution by means of computer simulation is demonstrated. The applications to in-circuit, real-time microwave impedance matching are suggested.**

I. Introduction

STUB-TUNING networks usually require in-field adjustments, in which an engineer manually adjusts the network while monitoring the SWR (standing wave ratio) or reflection coefficient (Γ) of the feed line. This manual process requires experience and can be tedious. This paper describes an innovative approach that applies a neural network to control this tuning process automatically.

II. Neural Network Background

Recently, researchers have applied the neural computing technique to microwave engineering [1]. A neural network consists of many processing elements, or neurons, each connected to many others [2]. Every connection entering a neuron has a weight assigned to it. This weight is used to amplify, attenuate, and change the sign of the signal in the incoming connection. An input vector is entered into the network. Each neuron operates on the outputs of other neurons according to its transfer function and delivers a single output to other neurons. Often, the transfer function sums the incoming signals to determine the value of the neuron's next output signal. The result is an output vector representing some characteristics associated with the input.

An N neuron Hopfield network is a bidirectional neural network which has the following characteristics [3]. If the activation of a neuron is updated according to

$$V_i(t+1) = \mathrm{sgn}\left(\sum_{i=1}^{N} T_{ij}V_j(t) + I_i\right), \qquad (1)$$

where $V_i(t) \in \{0,1\}$ is the output value of neuron i at moment $t, T_{ij} = T_{ji}$ is the weight associated with the link between neurons i and j, I_i is the internal threshold parameter of neuron i, and

$$\mathrm{sgn}(x) = \begin{cases} 1, & x > 0, \\ 0, & x < 0, \end{cases} \qquad (2)$$

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TABLE I
A Qualitative Model Of The Stub-Tuning Process

Current Adjustment Direction (V_1)	Change in SWR (V_2)	Next Adjustment Direction (V_3)
↓(0)	↓(0)	↓(0)
↓(0)	↑(1)	↑(1)
↑(1)	↓(0)	↑(1)
↑(1)	↑(1)	↓(0)

it can be shown that an energy function defined as

$$E = -\frac{1}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} T_{ij}V_iV_j - \sum_{i=1}^{N} I_iV_i + K, \qquad (3)$$

where K is a constant, is minimized. In other words, a Hopfield network will evolve to produce a combination of V_i's that result in a minimum of the energy function E.

III. Automatic Impedance Matching

A Hopfield network is developed to control the adjustment of stub locations and lengths. The Hopfield network qualitatively analyzes the change of SWR (or Γ) and determines the stub adjustment direction. The relationships between the stub adjustment and the SWR are qualitatively analyzed in Table I, which serves as a qualitative model for the tuning process. In Table I, ↑ (encoded as 1) and ↓ (encoded as 0) indicate an increment and a decrement, respectively.

Fig. 1 shows a Hopfield network that is developed to represent the qualitative model of Table I. The neuron outputs V_1, V_2, and V_3 represent the current adjustment direction, the change in SWR, and the next adjustment direction, respectively. The additional neuron (V_4) does not have any physical correspondence to the model, but is provided to ensure that the network has an energy E of 0 for any of the 4 consistent combinations ($V_1V_2V_3 = 000, 010, 101, 110$) shown in Table I while the remaining 4 inconsistent combinations ($V_1V_2V_3 = 001, 011, 100, 111$) have $E > 0$. This network was developed by using (3) to formulate a linear programming problem. The unknown T_{ij}'s and I_i's are solved by the simplex method [4]. Literature such as [5] can be consulted for a more detailed discussion of the construction of Hopfield networks. When this network is updated according to (1), the next adjustment direction is determined by the current direction and the change in SWR.

IV. Impedance Matching Network Synthesis

One obvious use of this approach is to synthesize stub-networks by means of computer simulation. This approach

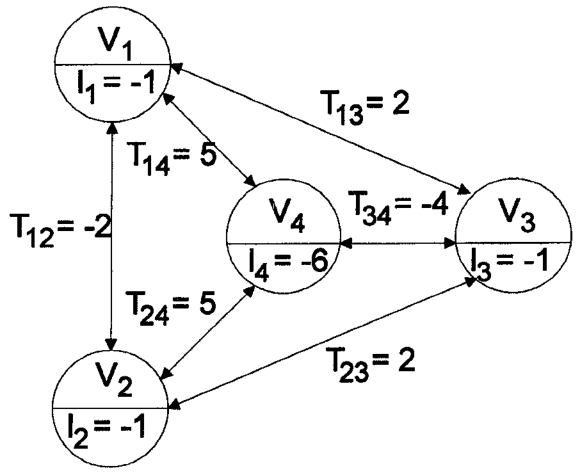

Fig. 1. The neural network controller.

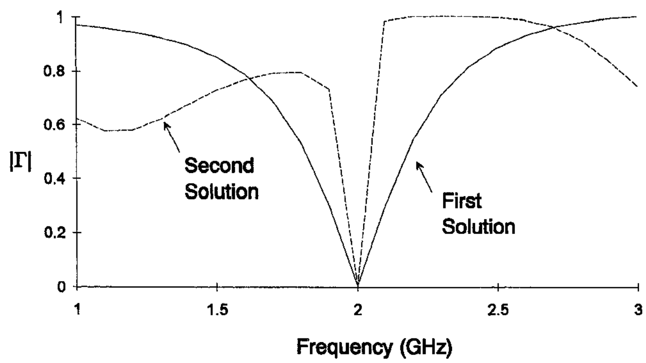

Fig. 2. Reflection coefficient magnitudes versus frequency.

has been tested by designing single- and double-stub tuners with open- or short-circuited stubs. A short-circuit double-stub shunt network is designed to match a load impedance of $Z_L = 100+j80$ to a 50-Ω line at the center frequency of 2 GHz. The spacing of the stubs in this network is chosen to be $\lambda/8$ and the first stub is placed at the load. Fig. 2 shows the performance of the stub-networks found ($l_1 = 0.3274\lambda, l_2 = 0.1003\lambda$, and $l_1 = 0.4249\lambda, l_2 = 0.454\lambda$) by this approach, which agrees with the results obtained from conventional analytical methods.

V. In-Circuit Real-Time Impedance Matching

The ultimate potential of this approach is that it can be used in a microwave circuit for in-circuit, real-time impedance matching. A neuron is implemented with an integrator constructed of an operational amplifier and the weighted links between neurons are formed by resistors [3]. A neural network can thus be readily integrated with the microwave circuit that it is serving. However, the fact that the lengths of microstrips cannot be changed posed a problem in planar microwave circuits. Two solutions to this problem are suggested in Figs. 3 and 4. Fig. 3 shows an approach developed for hybrid circuits. A technique similar to the integral contacts described in [6] is used. The length of a microstrip is changed by pressing a block of silicone rubber with a small conductor strip at its bottom onto a microstrip. The output of the neural network is used to mechanically slide the block on the microstrip. Fig. 4 shows an electronic approach to adjust the microstrip length

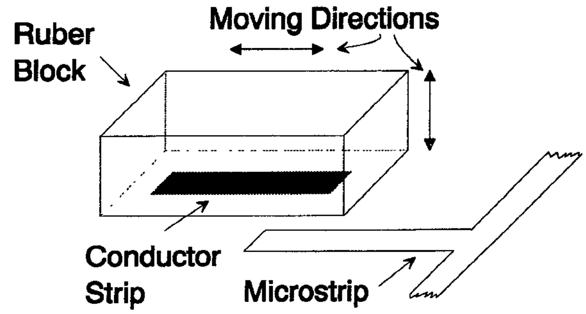

Fig. 3. An implementation for an adjustable-length microstrip in a hybrid circuit.

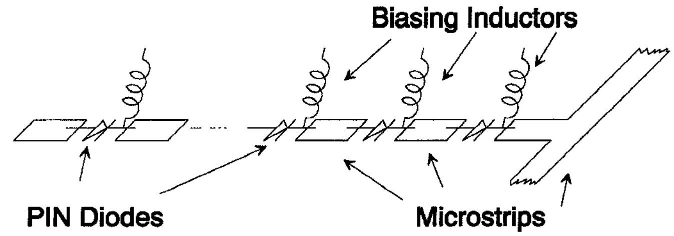

Fig. 4. An implementation for an adjustable-length microstrip in an MMIC.

and is especially suitable for MMIC's. The output of the neural network is encoded to selectively turn on (or off) PIN diodes to switch in (or out) microstrip sections. The effective stub length and thus its impedance is then adjusted.

VI. Summary

In summary, a novel technique which uses a neural network to adjust a stub-tuning network is developed. The adjustment of the stub locations and lengths is fully automated and is thus precise. In addition to being used as a computer method for synthesizing stub-tuning networks, it can be developed into an in-circuit, real-time adjustable broadband impedance matching network.

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