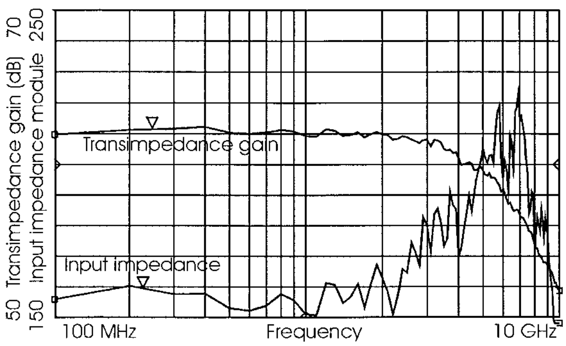

Figure 3 Measured input impedance and transimpedance gain of the transimpedance amplifier

gain of 62.5 dBΩ (50 Ω loaded at each output, photoreceiver capacitance of 0.15 pF), a −3 dB cutoff frequency of 5.6 GHz, and an input impedance of 150 Ω, shown in Figure 3.

Moreover, an input-equivalent noise current of 12.3 $pA/\sqrt{Hz}$ in the 100 MHz–7.5 GHz band has been evaluated by simulation, using the foundry library noise models for active and passive devices.

5. CONCLUSION

A novel topology of single-input to differential-output converters suitable for designing differential output transimpedance amplifiers has been proposed.

The converter provides 6 dB extra gain with respect to a simple differential pair, and allows us to design transimpedance amplifiers featuring improved performance in terms of conversion gain, input impedance, and offset compensation with respect to commonly used transimpedance topologies.

A front-end amplifier for SDH systems operating at 10 Gbit/s has been designed and fabricated in Philips PML ED02AH GaAs HEMT technology (0.2 μm gate length).

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GENETIC-ALGORITHM OPTIMIZATION OF DIPOLE EQUIVALENT-CIRCUIT MODELS

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ABSTRACT: *In this paper, we use a genetic-algorithm (GA) technique to optimize equivalent-circuit models of an antenna system. Two broadband equivalent-circuit models with component values are optimized by use of the genetic algorithm. The first is a conventional RLC network, while the second introduces a new technique that makes use of transmission-line segments as well as lumped components. Both equivalent circuits exhibit good impedance fidelity over a bandwidth exceeding five octaves, including the fundamental through the fourth overtone response.* © 2000 John Wiley & Sons, Inc. Microwave Opt Technol Lett 27: 259–261, 2000.

Key words: *genetic algorithm; equivalent circuit; antenna self-impedance*

I. INTRODUCTION

It is often desirable, when analyzing antenna systems, to have an accurate, yet simple lumped-component equivalent-circuit representation of antenna self-impedance over a broad frequency band. An equivalent circuit in this sense is a network of components that has a terminal frequency-impedance function essentially equivalent to an actual antenna. While the literature has many references to antenna equivalent circuits, most are narrowband representations. References [1] and [2] are exceptions to this general rule. The first reference describes an antenna equivalent-circuit model design technique, suitable for broadband representation, but having limited accuracy. The second reference describes more complex equivalent-antenna-circuit models having better broadband accuracy.

In this paper, we demonstrate the use of a genetic algorithm [3] to optimize a conventional lumped-component antenna equivalent-circuit model for the best impedance fidelity over a broad band. We then introduce a new antenna optimization circuit model, based upon transmission-line segments, that is simpler and has better broadband characteristics than the lumped-component model. The equivalent-circuit models presented here represent wire dipoles. They could also be useful in the representation of other antenna systems with similar frequency-impedance characteristics.

II. GA OPTIMIZATION OF LUMPED-COMPONENT EQUIVALENT CIRCUIT

The antenna equivalent-circuit model originally introduced in [2] is shown in Figure 1. The technique used to create the equivalent circuit is based upon point matching at critical frequencies. A series capacitor is selected to match antenna reactance at a very low frequency. A series inductor generates the reactance zero at half-wave resonance. A parallel resonant *RLC* network creates the full-wave resonance, with an additional *RLC* network required for each overtone response to be represented. However, it was found that the equivalent circuits in [2] are limited representations of wire dipoles and, therefore, in certain cases, they fail to represent

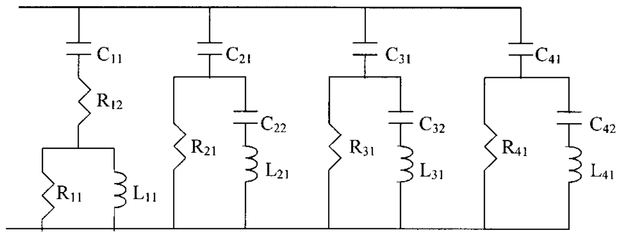

Figure 1 LCR dipole equivalent-circuit model

the true frequency response of a wire antenna. One example that was considered is a $\frac{1}{2}$ m long center-fed wire antenna with a 1 mm radius. In this case, the fidelity of the equivalent circuit presented in [2] was very poor, and consequently, some form of circuit optimization is required.

A genetic-algorithm technique was then used to optimize the equivalent circuit of the dipole antenna. The GA views the target antenna impedance, computed from a method-of-moments (MoM) computer code [4], as the design objective, and strives to select component values of the equivalent circuit to best match the desired impedance curves. A 10 bit binary-coded gene represents the value of each of the components. Therefore, a candidate antenna equivalent circuit is represented by a single 160 bit chromosome. The population size in this example is chosen to be equal to the chromosome size. The objective function is given by

$$F = \sum_{n=1}^{N_f} \left[(\mathrm{Re}^{\mathrm{MoM}}(f_n) - \mathrm{Re}^{\mathrm{GA}}(f_n))^2 + \left(\mathrm{Im}(f_n)^{\mathrm{MoM}} - \mathrm{Im}^{\mathrm{GA}}(f_n)\right)^2 \right]$$

where N_f is the number of frequency points, and $\mathrm{Re}^{\mathrm{Mom}}(f_n)$ and $\mathrm{Im}^{\mathrm{MoM}}(f_n)$ are the real and imaginary parts of the antenna impedance computed by the method of moments. $\mathrm{Re}^{\mathrm{GA}}(f_n)$ and $\mathrm{Im}^{\mathrm{GA}}(f_n)$ are the real and imaginary components of the equivalent circuit model chosen by the GA.

Figure 2 depicts the optimized results, which clearly illustrate a good agreement between the impedance of the genetically optimized antenna equivalent circuit and the antenna impedance computed by MoM. The model component values selected by the GA are listed below:

$R_{11} = 3.92\ \mathrm{k}\Omega$	$R_{31} = 4.24\ \mathrm{k}\Omega$
$R_{12} = 0.903\ \Omega$	$C_{31} = 0.183$ pF
$C_{11} = 1.21$ pF	$C_{32} = 0.100$ pF
$L_{11} = 261$ nH	$L_{31} = 186$ nH
$R_{21} = 5.36\ \mathrm{k}\Omega$	$R_{41} = 1.24\ \mathrm{k}\Omega$
$C_{21} = 0.241$ pF	$C_{41} = 0.185$ pF
$C_{22} = 0.517$ pF	$C_{42} = 0.367$ pF
$L_{21} = 206$ nH	$L_{41} = 35.4$ nH.

One disadvantage of the lumped-element model is the fact that each additional overtone resonance requires another circuit branch and the recalculation of all model elements. Furthermore, the sensitivity of the model component values seems to increase with the addition of overtone circuit branches. This is a fundamental problem rooted in the fact that antennas have overtone responses, but lumped circuit elements do not.

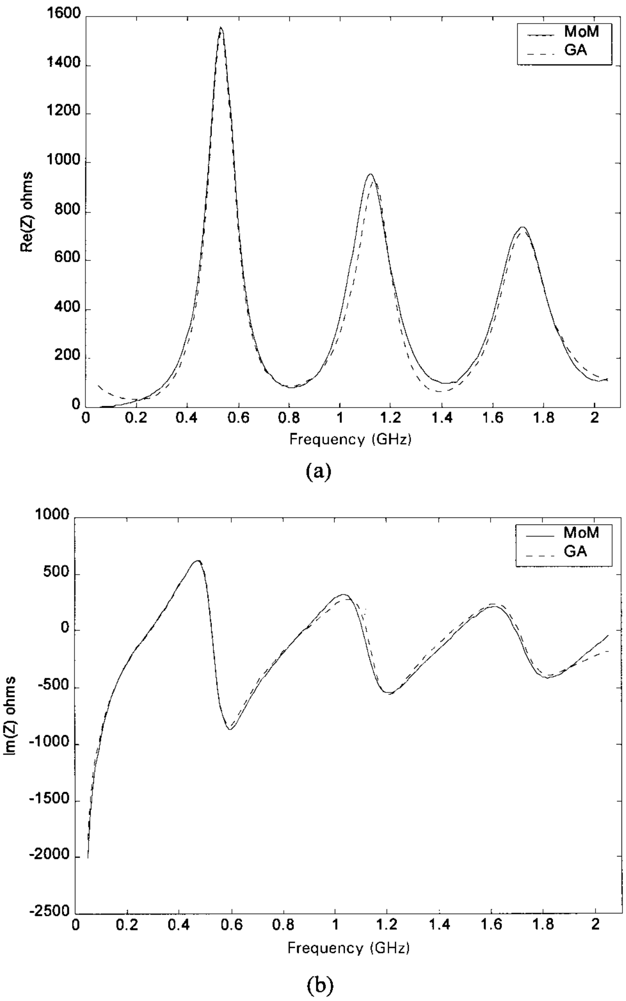

Figure 2 Impedance from MoM and from the GA-optimized equivalent circuit. (a) Real part of the impedance. (b) Imaginary part of the impedance

III. GA OPTIMIZATION OF LUMPED-COMPONENT TRANSMISSION-LINE EQUIVALENT MODEL

It then makes sense to consider an antenna equivalent-circuit model built around components that, like the target antenna, have periodic frequency-domain impedance behavior. Figure 3 shows such a model consisting of a pair of transmission-line sections—one mismatched into a high-impedance load, the other mismatched into a low-impedance load—in series with a capacitor. This simple model has repetitive reactance poles and zeros very similar to an actual dipole. The series capacitor improves the model accuracy at low frequencies. Both transmission lines are about one-eighth wavelength long at the first half-wave resonance.

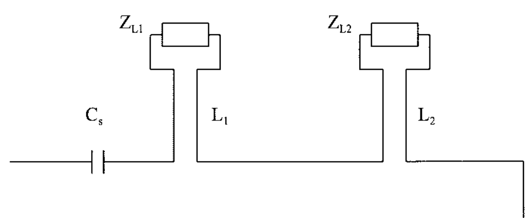

Figure 3 Simplified transmission-line equivalent-circuit model

To further improve the model fidelity, the lumped-impedance loads are added at both ends of the transmission lines. Figure 4 shows an antenna equivalent-circuit model with improved impedance fidelity where negative capacitors are included in the load networks. Because negative capacitors have positive reactance, they shift the full-wave resonance frequencies downward, and because the magnitude of this reactance decreases with frequency, the fundamental resonance is affected more strongly than the overtones, thereby improving the correspondence between the circuit model and actual antenna impedance poles. The transmission lines themselves are allowed to be lossy, with the loss increasing with frequency. Again, the GA is applied to select the parameter values needed for model accuracy. The transmission-line segments are modeled using the standard hyperbolic trigonometric relationship with a complex propagation constant γ [5], where $\gamma = \alpha + j\beta$, $\beta = 2\pi/\lambda$, and α is one of the parameters which will be optimized by the GA. Figure 5 shows the optimized results. The component values selected by the GA are given below:

$R_{11} = 13.11\ \Omega$	$R_{21} = 699.7\ \Omega$
$R_{12} = 3600\ \Omega$	$R_{22} = 1100\ \Omega$
$R_{13} = 500\ \Omega$	$R_{23} = 330.0\ \Omega$
$C_s = 2.504$ pF	$C_{21} = 0.2938$ pF
$C_{11} = -16.25$ pF	$C_{22} = -0.020$ pF
$C_{12} = 0.4000$ pF	$C_{23} = -0.030$ pF
$C_{13} = 0.1388$ pF	

line L_1 $Z_o = 214.8\ \Omega$, length = 0.1248 M,
line L_2 $Z_o = 195.1\ \Omega$, length = 0.1304 M,

$$\alpha = 0.0744 + 0.3000\,[\log_{10}(f/900\text{ MHz})]$$
$$\alpha = 0.0101 + 0.0339\,[\log_{10}(f/90\text{ MHz})].$$

We noticed that transmission line L_1 dominates the odd-order full-wave resonances. Altering L_1 or its associated load networks changes the first and third full-wave resonances with little effect on the second and fourth. The second line and associated lumped components chiefly affect the even-order resonances. Series *RC* branches have an increasing effect at higher frequencies.

IV. CONCLUSIONS

We have demonstrated the use of a genetic algorithm to improve the impedance fidelity of two broadband antenna equivalent-circuit models for a dipole. In the first example, a GA is used to optimize component values in a lumped *RLC* network. In the second example, the authors present a novel transmission-line-based antenna equivalent-circuit model, and again determine optimum model parameters with the use of a genetic algorithm. The second equivalent-circuit model exhibits quite good impedance fidelity over a bandwidth exceeding five octaves, including the fundamental through the fourth overtone response.

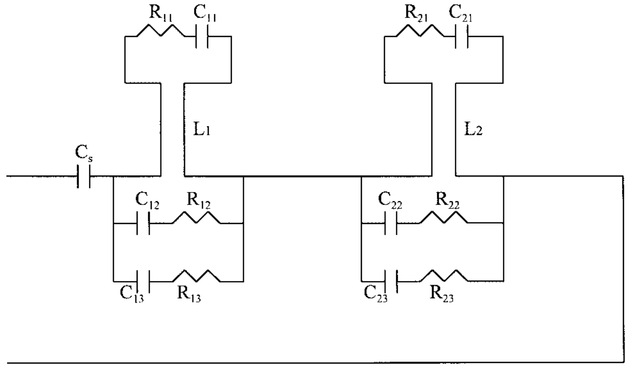

Figure 4 Antenna equivalent-circuit model with improved impedance fidelity

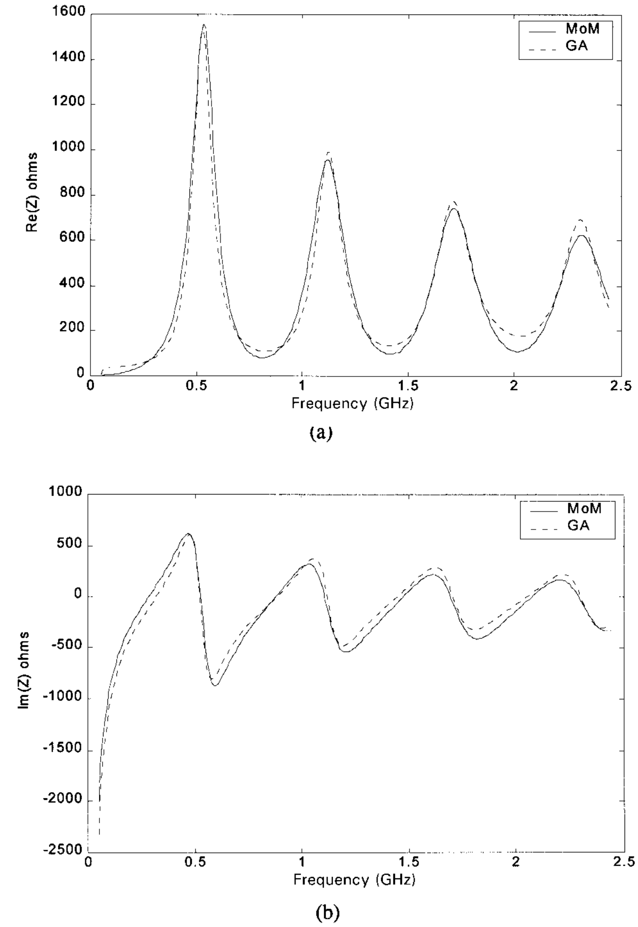

Figure 5 Impedance from MoM and the GA-optimized transmission-line-based dipole equivalent circuit. (a) Real part of the impedance. (b) Imaginary part of the impedance

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