Genetic Algorithm Design of Electronic Analogue Circuits Including Parasitic Effects

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Abstract:

An extended Genetic Algorithm method is described that allows parasitic effects in components to be included in the design of analogue electronic circuits built from components with values selected from a set of predetermined 'preferred' values. An example is given showing that successful circuit solutions can be obtained that fail with previous methods.

Introduction

In the conventional approach to the design of analogue electronic circuits, components are assumed that are ideal and have unrestricted values. The design is then made practical by selecting actual component values from a discrete set of manufactured 'preferred' values. The usual criterion used is to take the nearest preferred values to the ideal values. However this step may take the circuit out of the specified performance, and the design thus fails.

An alternative approach is to perform the design in the discrete domain of component values that are restricted to preferred values. This becomes a highly-complex combinatorial search problem. It has been successfully tackled for examples of active and passive filters using a genetic approach, [3-6].

The other practical consideration is that of components being non-ideal due to associated parasitic components. This paper shows how the previously published work can be extended to allow genetic search that incorporates parasitic effects. Illustrative results are given for the example of a seventh-order low pass resistively terminated LC filter, figure 1. In the example a successful design is obtained that fails when previous genetic methods are used.

Parasitic Effects

Practical components differ from ideal ones due to a number of differing physical causes. For this study the equivalent circuits that model the main effects have been employed as shown in figure 2, where C_S are stray capacitances, R_S is the equivalent loss resistance of the inductor, and G_S is the equivalent dielectric loss conductance of the capacitor, [7].

In addition to component parasitics, the circuit interconnections can be non-ideal , and are modelled here as stray capacitances between adjacent node pairs.

The method described can be applied to other forms of models of circuit non-idealities.

Implementation

A conventional genetic algorithm (GA) was used in this application [1,2], for which (i) *representation method*, (ii) *fitness function*, and (iii) GA *operators and control parameters,* needed to be defined.

The fixed structure circuit is *represented* by a binary valued gene comprising nine sections, one for each component in the circuit, figure 1. Each section comprises a group of bits which are used to address a table of preferred component values to be used in the circuit design. For the example below, six bits were sufficient for the 'twelve-series' preferred values chosen spanning four decades.

The basis of the *fitness function* is the calculation of the frequency response over a uniformly spaced fine grid of frequency points, f_n , for each gene in the population. The nodal admittance matrix (NAM) formulation is chosen because the entries of the NAM are readily formed for ideal components by inserting at NAM locations corresponding to the component node numbers, admittances calculated according to $R^{-1}, j\omega C, (j\omega L)^{-1}$, respectively, where $\omega = 2\pi f$. The NAM equations are then solved using LU factorisation to give the voltage transfer function. To allow non-ideal components, this method has been extended by including in the table of preferred component values, the associated values of parasitic components. These are now employed by the full expressions for admittances of the equivalent circuits on the right of figure 2., for insertion in the NAM. For the circuit interconnection parasitics, terms of the form $j2\pi f C_s$ are entered in the NAM at the corresponding node positions. The frequency response is compared with the specified frequency response template and all deviations outside the template are summed. The reciprocal of this sum is used as the fitness. This method of fitness has the advantage over a more conventional approach using sum-squared deviations from a single ideal frequency response, in that rather than a single solution, a group solutions is now obtained by the GA, all of which satisfy the design specification.

For the *operators*, two-point cross-over is used with mutation applied at a uniform rate of 0.05. For the example presented here a population size of fifty was found to be satisfactory and the population was usually found to have stabilised in around a hundred generations.

Example

A seventh order low pass filter template specification was chosen with a maximum pass band ripple of 1dB and band edge at 10^5 rad/sec; and a relative stop band attenuation of -160 dB with a band edge at 10^6 rad/sec. In the transition band the response is unconstrained. The absolute value of pass band response was allowed to be freely determined by the GA within reasonable limits provided the pass band ripple and relative stop band attenuation were satisfied.

For the parasitic components, typical practical values were assumed of 10, 10, and 20 pF respectively for the parasitic capacitances of all resistors, capacitors and inductors. The inductor equivalent loss resistance was 10 ohms and the dielectric loss conductance of the capacitor was assumed to be negligible. Interconnection parasitics between the main nodes and ground were assumed to 20 pF.

Figure 3(a) shows the response of a typical solution from our earlier GA method using ideal components. This satisfies the template. When the above parasitic components are added to this circuit, the response in figure 3(b) is obtained which clearly fails. Using the method described here in which parasitic components are included in the GA, then figure 3(c) shows a typical solution from the group obtained. This appears to satisfy the specified template.

Conclusion

This extension to the previously described GA method allows parasitic components to be included in the evolutionary design process. The method can be readily used for designing any passive or active analogue circuit structure in which components are selected from a set with known equivalent circuit values.

Compute times were reasonable (typically 5 hours) for this example with the conventional GA used. However it would be desirable to improve on this to raise the limit of circuit size that can be designed. We have had some success using adaptive GA control parameter techniques. Also some benefit can be expected by using variable resolution frequency grids [8] for the calculation of the circuit response.

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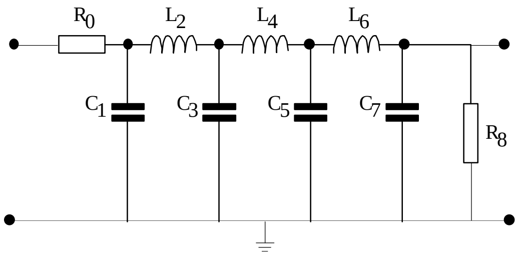

Figure 1 Low Pass All-Pole Ladder Structure

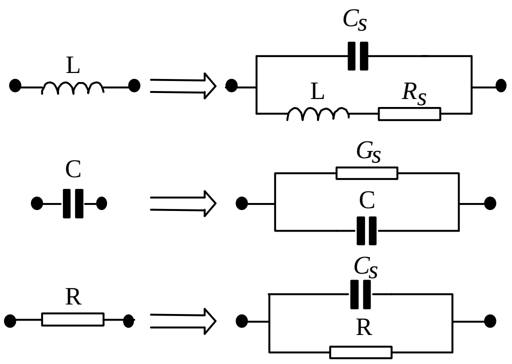

Figure 2 Passive components equivalent Circuits

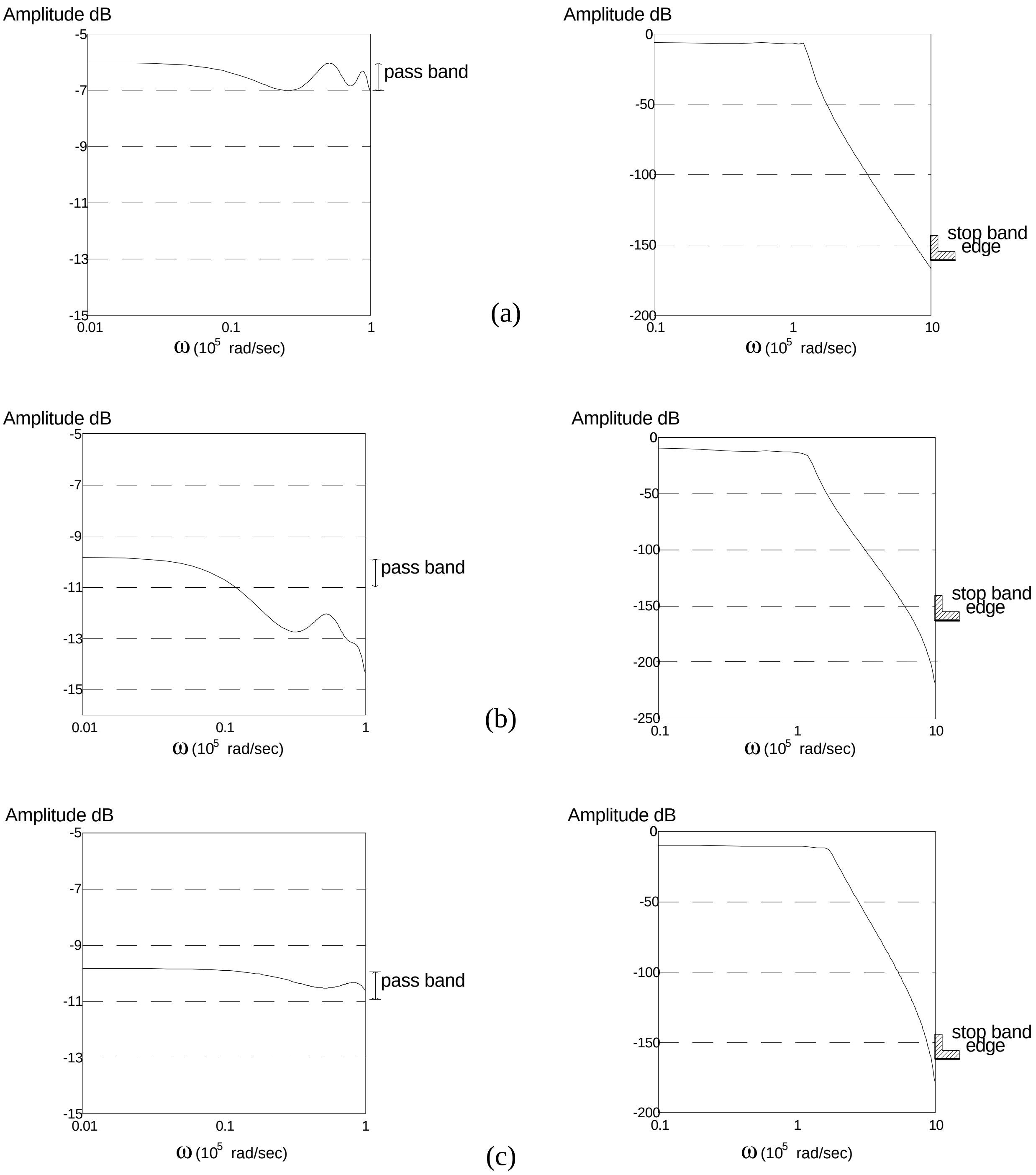

Figure 3 (a) Response of Genetically derived LC ladder filter with no parasitics considered.
(b) Response of the filter in (a) after adding the expected parasitic effects.
(c) Response of Genetically derived LC ladder filter with arasitics considered