RF Filter Design Using Insertion Loss Method And Genetic Optimization Algorithm

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ABSTRACT
A filter design using insertion loss method (ILM) and Genetic Algorithm (GA) is presented in this paper. Many techniques have been proposed for the design and analysis of filter circuit, but the insertion loss method is generally preferred for the flexibility and accuracy that it provides. The ILM is based on network synthesis techniques and can be used to design filter having a specific type of frequency response. However, this procedure is not practical for a large number of elements. GA algorithm can be a useful procedure for calculating values in filters with a large number of elements. This paper presents the procedure which takes an advantage of ILM for filter design and GA for determination of an unknown value in filters with large number of elements. This is suitable approach for filter design with an arbitrary shape of cutoff frequency and pass band.

Keywords **–** Genetic Algorithm, insertion loss method, RF filters

I. INTRODUCTION
Filters are ubiquitous building blocks in wireless systems. Filters are two-port networks used to control the frequency response and they are present in just about every piece of electronic equipment (radios, television, analog-to-digital converters, computers etc.). There are four possible frequency responses lowpass, highpass, bandpass and bandstop. Filters can be analog or digital. Furthermore, analog filters can be passive or active. Passive filters use only resistors, capacitors, and inductors. [2]

There are several methods available for the design of filter networks, such as image parameter, constant-*k*, *m*-derived, composite filter, insertion loss, Butterworth (maximally flat), Chebyshev (equal ripple) and elliptic filter methods. In a common classical procedure, a lowpass (LP) filter is first designed with the normalized source impedance and cutoff frequency, and then it is converted to the desired highpass (HP), bandpass (BP) and bandstop (BS) characteristics by appropriate filter transformations [4 5]. The filter specifications such as the ripple level in the pass band and attenuation in the stop band will determine the filter order. Then, the values of reactive elements are obtained. In such design procedures, the filter topology is limited to some specific configurations and the filters are lossless. On the other hand, the source and load impedances are usually Assumed real and equal. For some designs (such as Chebyshev filter with even order) these impedances are constrained to certain values, which require some appropriate impedance matching circuits in the input and output ports of the filters [5]. However, in this paper, we are concerned with the design of lumped filters, which have direct applications for microwave distributed filters, which may be realized through the application of appropriate transformation formulas [4 5].

II. FILTER DESIGN
1.1 Filter design by Insertion loss method
The ideal filter would have zero insertion loss in the passband, infinite attenuation in the stop, and a linear phase response(to avoid signal distortion) in the passband, Of course, such filters do not exist in practice, so compromises must be made; herein lies the art of filter design.
The insertion loss method allows a high degree of control over the passband and stopband amplitude and phase characteristics, with a systematic way to synthesize a desired response. The necessary design trade-offs can be evaluated to best meet the application requirements. If, for example, a minimum insertion loss is most important, a binomial frequency response can be used; a Chebyshev response would satisfy a requirement for the sharpest cutoff. If it is possible to sacrifice the attenuation rate, a better phase response can be obtained by using a linear phase filter design. And in all cases, the insertion loss method allows filter performance to be improved in a straightforward manner, at expense of a higher order, or more complex, filter.

The ILM is based on network synthesis techniques. The technique begins with the design of a low pass filter prototype that is normalized in terms of impedance and cutoff frequency. Impedance and frequency scaling and transformations are then used to convert the normalized design to the one having the desired frequency response, cutoff frequency, and impedance level. Additional transformations, such as Richard’s transformation, impedance/admittance inverters, and the Kuroda identities, can be used to facilitate filter implementation in terms of practical components such as transmission lines sections, stubs and resonant elements.

1.1.1 Characterization by power loss ratio

In this method a filter response is defined by its insertion loss or power loss ratio, *PLR* [5]

$$PLR = \frac{Pinc}{Pload} = \frac{1}{1-|\Gamma(\omega)|^2} \quad (1)$$

$$PLR == \frac{1}{|S21|^2} \quad (2)$$

Where Γ(ω) is the reflection coefficient seen looking into the filter. Since the normalized input reflection coefficient is:

$$\Gamma = \frac{Zin-1}{Zin+1} \quad (3)$$

The power loss ratio for a maximally flat low-pass filter is [5]:

$$PLR = 1 + k^2\left(\frac{\omega}{\omega c}\right)^{2N} \quad (4)$$

where the passband is the region from ω=0 to the cutoff value ωc , k^2 is the passband tolerance and *N* is number of filter elements (Fig. 1.) For ω > ωc the power loss ratio increases at a rate dependent on the exponent *2N* which is related to the number of filter elements. In addition, for sharpest *PLR* characteristic over cutoff frequency larger number of filter elements are needed.

For equal-ripple low-pass filter prototype (Chebyshev filter) power loss ratio is:

$$PLR = 1 + k^2 T_N^2\left(\frac{\omega}{\omega c}\right) \quad (5)$$

where *TN(x)* is a Chebyshev polynomial of order N what will result with a sharper cutoff characteristic, although the passband response will have ripples (1+k2) of amplitude. Using (3) or (4) we are able to calculate required characteristic of filter and then calculate unknown values of element. But, for large number of *N* analytical procedure for determining filters elements is very laborious.

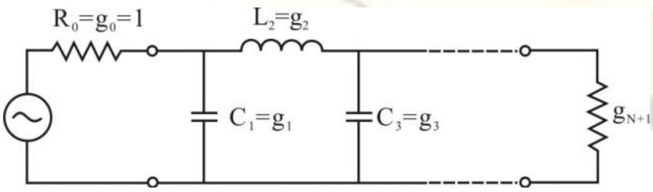

Fig.1. Low pass filter prototype with N elements

1.1.2 Denormalization of standard low pass design

To arrive at realizable filter, we have to denormalize the coefficients to meet realistic frequency and impedance requirements. In addition, the standard low pass filter prototype should be convertible into high-pass or bandpass/bandstop filter types depending on the application. These objectives can be achieved by considering two distinct steps: [4]

Frequency transformation to convert from normalized frequency Ω to actual frequency ω. This step implies the scaling of the standard inductance and capacitances.[4]

Table 1. Equivalent circuits for transformation of normalized lowpass filter to other filter types.

Low-pass	High-pass	Band-pass	Band-stop
$\frac{L}{\omega_p}$	$\frac{1}{\omega_p L}$	$\frac{L}{\omega_0\Delta}$, $\frac{\Delta}{\omega_0 L}$	$\frac{1}{\omega_0 L\Delta}$, $\frac{L\Delta}{\omega_0}$
$\frac{C}{\omega_p}$	$\frac{1}{\omega_p C}$	$\frac{C}{\omega_0\Delta}$, $\frac{\Delta}{\omega_0 C}$	$\frac{1}{\omega_0 C\Delta}$, $\frac{C\Delta}{\omega_0}$
where: $\omega_p = 2\pi f_p$, $\Delta = \frac{\omega_{Up}-\omega_{Lp}}{\omega_0}$, $\omega_0 = \sqrt{\omega_{Up}\omega_{Lp}}$			

Impedance transformation to convert standard generator and resistances g_0 and $g_{(N+1)}$ to actual resistances R_L and R_G. Entire impedance expression need to scale. This is accomplished by scaling all filter coefficients by actual resistance R_G. That is, [4]

$R_G' = 1R_G$ (6)

$L' = 1LR_G$ (7)

$C' = C/R_G$ (8)

$R_L' = R_L R_G$ (9)

1.2 Filter design by Genetic optimization algorithm

2.2.1. Basic of GA

GA is a part of evolutionary computing, which is a rapidly growing area of an Artificial Intelligence. Genetic Algorithm (GA) is essentially a search and optimization technique. Inspired by Darwin's Natural selection theory of Biological Evolution(1859) and Genetics(1885). First GA was developed by john Holland 7 his students in 1975. The concept in the theory of Biological Evolution has been translated into GA to search for an optimal solution to a problem in a more 'natural' way.

For GA, the chromosome is the basic unit that encodes a possible solution to a problem in a given search space. The set of chromosomes is called as population that represents set of solutions to the problem. In GA, the population is evolved with a hope that the new population will be better than the old one. The evolution process consists of successive generations. At each generation, the population is evolved using responses from its environment and stochastic-genetic operators (i.e.

selection, crossover and mutation) to create the new population of fitter solutions.

The GA when applied for filter design begins with an initial, random population of set of chromosomes (each chromosome represents a set solutions i.e. filter elements like L & C). This population is then evolved, over generations, using responses from its fitness function and stochastic genetic operators (i.e. selection, crossover and mutation) to produce the most optimum values of filter elements.GA searches the optimal filter elements without concerning itself with the working of RF filter. The fig. 2 shows the operation of GA based RF filter design.

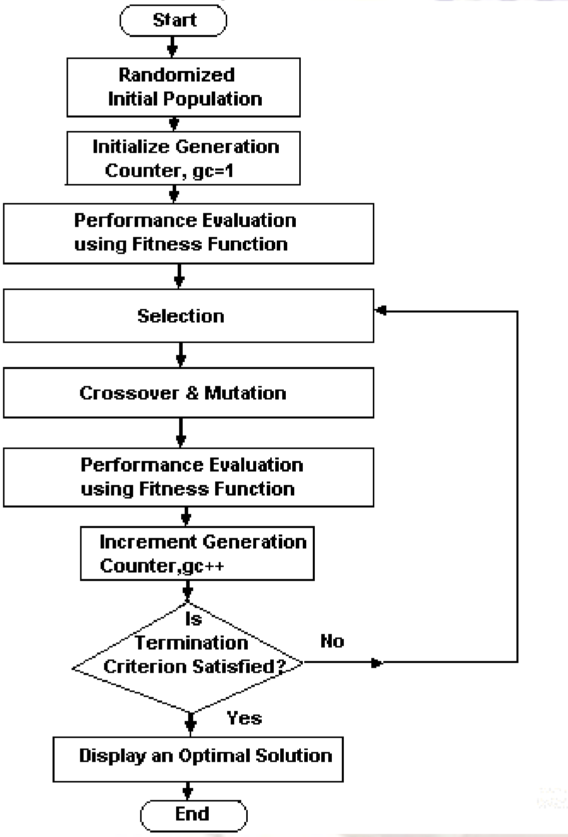

Fig.2 Flowchart of GA Optimization Process

To design RF filter by GA, one m-file was written that includes an initialization of essential GA parameters and call to main GA function to find the optimal RF filter elements. However, merely this m-file does not provide optimum RF filter elements, but it also requires a suitable fitness function.m file to evaluate the fitness values of population individuals (chromosomes).

2.2.2. Fitness function

The key to GA implementation for RF filter design is the evaluation of fitness values of population individuals. Since each population individual i.e. chromosome represents a set of filter elements, it is assigned with fitness value based upon its performance. The actual fitness evaluation is performed by designing filter by Insertion Loss Method (ILM) and calculating S-parameters for different frequency points. Then the filter elements are selected using GA and again S-parameters are calculated for different frequency points. Then the total error between S-parameters calculated using ILM and using GA is found. The smaller the total error better the performance and hence larger the fitness value of given set of filter elements.

The fitness value is defined by

$$F = \frac{\sum_{i=1}^{N} \omega_i f_i}{N} \quad (10)$$

where ωi represents the weighting value at the i th sampling
point, fi is the square of the difference between the magnitude of the calculated scattering parameter and the desired value at the i th sampling point, and N is the number of sampling points.

III. RESULTS

In this section the comparison between analytically (ILM) calculated S21 and S21 obtained by GA method is illustrated using different examples. We consider S21 for
maximally flat filter (see Fig. 3.to Fig. 6) for different number of elements. It can be seen that there is a good agreement between S21 calculated analytically and by GA method.

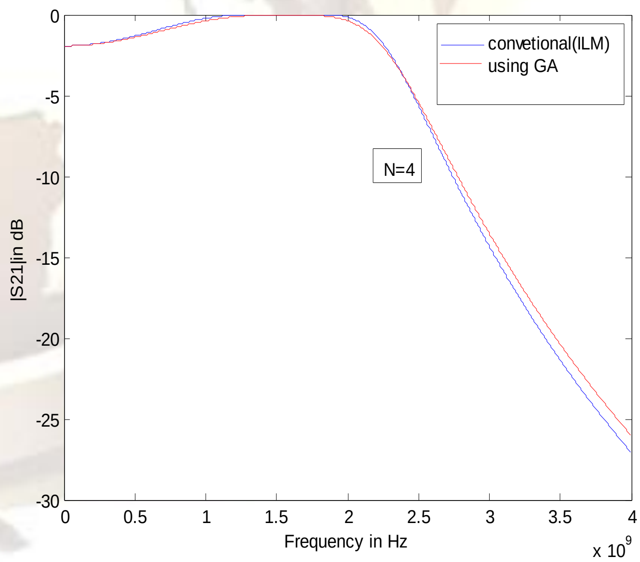

Fig.3. Conventional (ILM) versus GA |S21| for maximally flat low-pass filter with 4 elements

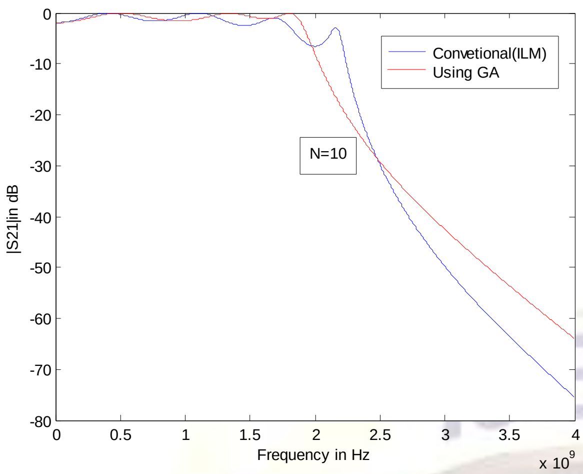

Fig.4. Conventional (ILM) versus GA |S21| for maximally flat low-pass filter with 10 elements

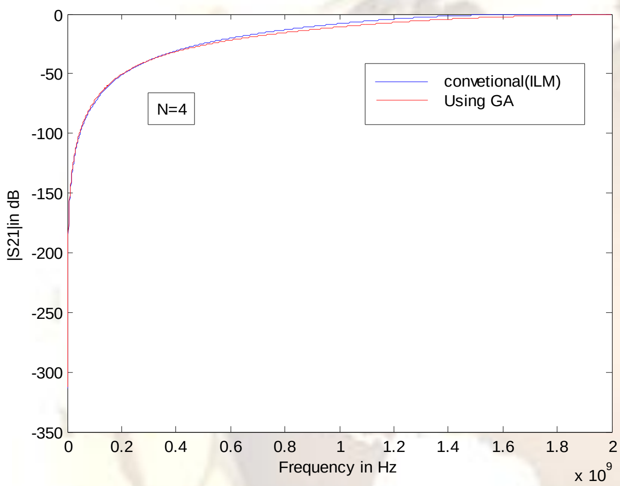

Fig.5. Conventional (ILM) versus GA |S21| for maximally flat High-pass filter with 4 elements

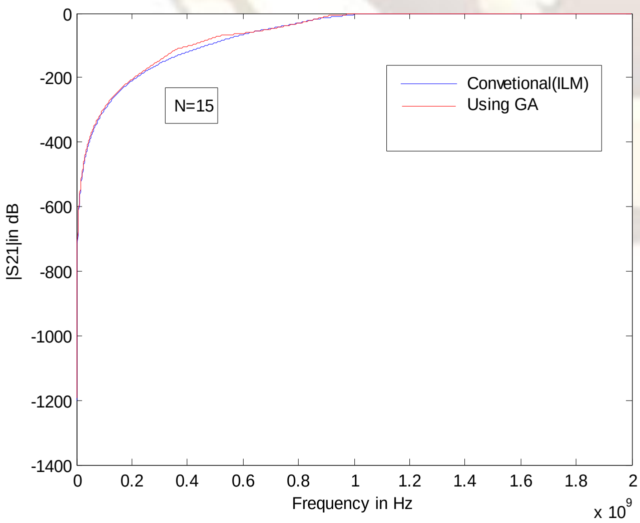

Fig.6. Conventional (ILM) versus GA |S21| for maximally flat High-pass filter with 15 elements

Als0 we consider S21 for equal ripple (Chebyshev) filter (see Fig. 7.to Fig. 8) for different number of elements. It can be seen that there is a good agreement between S21 calculated analytically and by GA method.

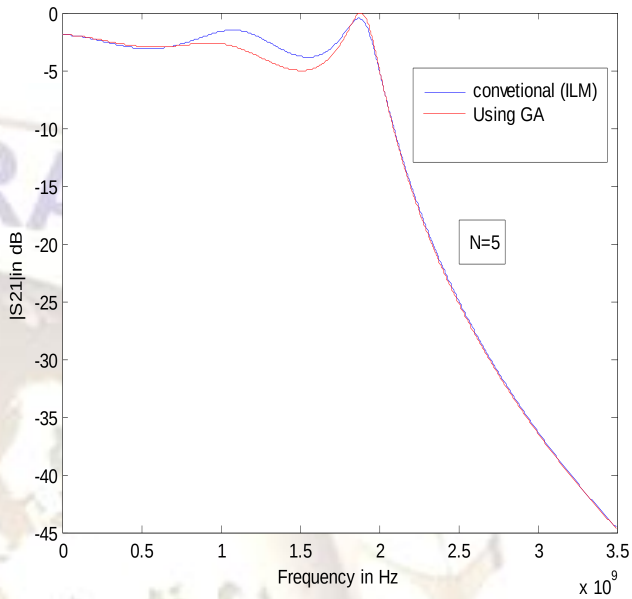

Fig.7. Conventional (ILM) versus GA |S21| for equal-ripple Low pass filter with 5 elements

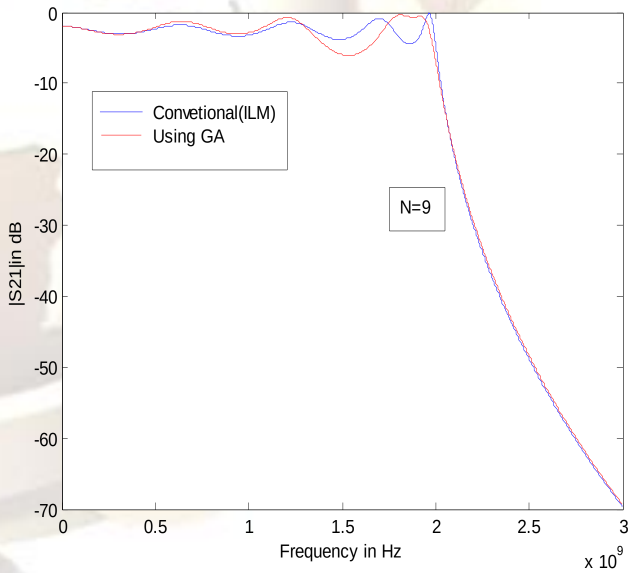

Fig.8. Conventional (ILM) versus GA |S21| for equal-ripple Low pass filter with 9 elements

IV. CONCLUSION

In this paper two approaches for RF filter design have been discussed, one approach is classical approach based upon insertion loss method while newer- proposed approach is based upon evolutionary algorithm -Genetic Algorithm. Insertion loss method is generally used technique for the filter design with an arbitrary number of elements and can be used to create a filter which has different types of frequency responses. However, this procedure is not practical for a large number of elements. The proposed GA based method can be used to design RF filter with large number of elements. This new method is suitable approach for filter design with an arbitrary shape of cutoff frequency and pass band. A computer program was developed in MATLAB and tested. It can be seen that program gives good results and could be commercially used for filter design. Furthermore, it should be emphasize that this solution makes sense for the filters with large number of elements where the sharper cutoff characteristic is required.

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