Design of Compact SITLs Low Pass Filter by Using Invasive Weed Optimization (IWO) Technique

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Abstract **─** Step impedance transmission line (SITL) is optimized by Invasive Weed Optimization (IWO) technique to compact a low pass microstrip filter (LPF). In the proposed method, the uniform microstrip lines in the LPF structure are replaced by optimized SITLs. The equality of SITL and uniform transmission line gives two additional design parameters, which are optimized by IWO method to achieve the most compact SITLs. Finally, a compact high degree LPF is designed and fabricated with the area reduction of more than 70%. The measurement results of the fabricated LPF are in good agreement with the simulation ones.

Index Terms **─** Invasive weed optimization, low pass filter, and step impedance transmission line.

I. INTRODUCTION

Microstrip transmission lines are widely used in microwave circuits and play important roles in the microwave applications. In modern wireless communication systems, compact size and high performance devices are commonly required to reduce the cost and enhance system performances [1, 2]. Therefore, the miniaturization of microstrip transmission line devices has become a key issue for researchers, especially in low frequencies. Meandering of the transmission lines could be the most ordinary way for size reduction [3]. Moreover, the photonic bandgap (PBG) structure provides an alternative way for miniaturization [4-11]. Utilizing a slotted ground structure was reported in [12] as another way for size reduction and suppressing the spurious harmonics. Artificial transmission lines composed of microstrip quasi-lumped elements and their discontinuities are another approach for size reduction [13, 14].

Also, step impedance transmission lines (SITLs) and step impedance resonators (SIRs) are other ways to reduce the size of microstrip devices [15, 16]. In [17], the authors proposed a new idea based on SITLs in order to compact a quarter wave length transmission lines in the microstrip devices such as Wilkinson power divider. In this paper, we extend the idea to compact a microstrip transmission line with arbitrary specifications, electrical length, and characteristic impedance. In more details, the equality of the uniform and step impedance transmission lines ABCD matrices gives two equations with four unknown variables. It means that there are two degrees of freedom for solving the equations. Therefore, we used the Invasive Weed Optimization (IWO) algorithm to find the optimum answers of these equations to achieve the most equivalent compact SITL. This very simple algorithm inspired from the phenomena of colonization of invasive weeds in nature, achieves a reasonable performance compared with other numerical stochastic optimization algorithms such as GA and PSO [18-19]. Finally, the achieved SITLs with optimum values are used instead of the corresponding uniform transmission lines in a low pass filter structure. The simulation and fabrication results of the designed low pass filter show more than 70 % compactness in the proposed low pass filter.

II. STEP IMPEDANCE TRANSMISSION LINES (SITL)

Generally, step impedance transmission line (SITL) is a non-uniform transmission line that can be used in the microstrip circuits to reduce its size,

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shift the spurious pass band to the higher frequency, and even to suppress the multiple spurious pass bands.

Figure 1 shows a step impedance transmission line composed of a transmission line with the length of θ_2 and characteristic impedance Z_2 between two lines with the length of $\theta_1/2$ and characteristic impedance Z_1, which should be equivalent to a transmission line with the length of θ_0 and characteristic impedance of Z_0, at frequency f_0. For this purpose, two independent entries of the two equivalent structures ABCD matrices have to be equal with each other at frequency f_0. After some algebraic manipulations, we have the following independent relations,

$$\cos\theta_1 \cos\theta_2 - \frac{1}{2}(k_z + \frac{1}{k_z})\sin\theta_1 \sin\theta_2 = \cos\theta_0 \quad (1)$$

$$z_1 \sin\theta_1 \cos\theta_2 + \frac{z_1}{k_z}\sin\theta_2 \times \left[\cos^2\theta_1/2 - k_z^2 \sin^2\theta_1/2\right] = z_0 \sin\theta_0, \quad (2)$$

where Z_1, $k_z = Z_1/Z_2$, θ_1, and θ_2 are unknown variables. Therefore, we have two equations and four unknown variables. In other words, there are two degrees of freedom to design a step impedance transmission line instead of the uniform lines. To solve these equations, invasive weed optimization (IWO) technique can be used to reach the desired values of the most compact SITLs case.

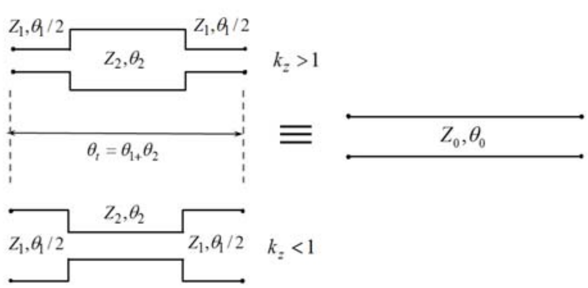

Fig. 1. The step impedance transmission line configuration.

III. OPTIMIZATION ALGORITHM DESIGN

IWO is a simple numerical stochastic search algorithm that mimics natural behavior of weed colonizing in the opportunity spaces for optimizing the function. Also, it has been shown to be effective in converging to an optimal solution by employing basic and simple properties such as seeding, growth, and competition in a weed colony. Some basic steps of the process are as follows [18-21]:

1) First, same as other stochastic algorithm, the parameters that need to be optimized, should be selected to determine the problem dimension, D. Then, for each of these variables, maximum and minimum values should be assigned.

2) Finite number of seeds, N, are spread out over the search area of the problem space with random positions.

3) Every seed grows to a flowering plant based on its fitness, which represents the goodness as a solution. Then each plant produces seeds depending on its own and the colonies lowest and highest fitnesses. In other words, the seeds number of each plant increases linearly from the minimum possible seed production level, S_{min}, to its maximum level, S_{max}, based on its fitness.

4) The produced seeds are being dispersed over the search area and grow to new plants by normally distributed random numbers with mean equal to the location of the producing plants and varying standard deviations. This ensures that the seeds will be randomly distributed near the parent plant. Also, the standard deviation (SD), σ, will be reduced from a previously defined initial value, $\sigma_{initial}$, to a final value, σ_{final}, in each iteration by,

$$\sigma_{iter} = \frac{(iter_{\max} - iter)^n}{iter_{\max}^n}(\sigma_{initial} - \sigma_{final}) + \sigma_{final} \quad (3)$$

where $iter_{max}$ is the maximum number of iterations, σ_{iter} is the SD at the present step and n is the nonlinear modulation index.

5) This process continues until the maximum number of the plants, P_{max}, is reached. Then, only the plants with high fitness can survive and produce seeds, and others are eliminated. The process will be stopped after the maximum number of iterations is reached and, hopefully, the plant with the best fitness will be the closest one to the optimal solution.

In our system equations, i.e., equations 1 and 2, we introduce the error function to achieve the most compact SITL as,

$$e = \sqrt{e_1^2 + e_2^2} \quad (4)$$

where e_1 and e_2 are the difference between the sides of equations (1) and (2), respectively for any given values (trial SITL). The fitness function of each trial SITL is introduced as below,

$$f = \begin{cases} w_1\theta_t + w_2 e & e < error \\ w_3\theta_t + w_4 e & e > error \end{cases} \quad (5)$$

where w_1, w_2, w_3, and w_4 are the assigned weights, θ_t is the total electrical length of trial SITL and *error* is a threshold for accepting a trail structure as a good enough answer for the equations. The optimization goal is to minimize the fitness function. The high w_3/w_1 and w_4/w_2 values separate two parts of the fitness function very well. To be more specific, with these conditions, the trial SITLs with $e < error$ compete with each other just according to their electrical length, θ_t, while ones with $e > error$ compete with each other to enter the $e < error$ region. Moreover, w_1/w_2 and w_3/w_4 determine the importance of *error* against the electrical length.

IV. LOW PASS FILTER EXAMPLE DESIGN

Here, a low pass filter is designed and implemented to validate the proposed approach. The filter is a seven element Chebychev with four shunt capacitors and three series inductors, 0.01 dB ripple and 460 MHz cut-off frequency. In the traditional implementation of the LPF, the shunt capacitors and series inductors can be modeled with open-stubs and high-z lines, respectively. We consider the TLX Taconic substrate with thickness h = 0.8 mm and relative dielectric constant ε_r = 2.55 for simulations and fabrication. The designed values of the traditional LPF are tabulated in Table 1. In this step, each capacitors and inductors are replaced with a SITL configuration. The optimized values of the equivalent SITLs for these four different lines (two open stubs and two high impedance lines) have been computed by the IWO method. The IWO parameters are tabulated in Table. 2. Based on the defined fitness function in equation (5), the optimization method tries to find the equivalent SITL instead of the uniform transmission line (answers of equations (1) and (2)) with the lowest θ_t in the search area. As shown in Table. 2, 10 Ω and 180 Ω are chosen as the lower and higher limitation of the impedance research area. Furthermore, θ_1 and θ_2 < $\theta_0/4$ guarantee that the optimized SITL electrical length is less than half of the conventional transmission line electrical length. Based on the different examples, it was concluded that selecting maximum and minimum number of seeds and non linear modulation index as 2, 10, and 3 leads to a good performance of the optimizer. Also, since the run time of the algorithm is very low, the number of initial population and maximum number of plant population are selected as high as 80 to achieve more accuracy in the method. Moreover, by choosing $\sigma_{initial}$ = 0.01, the error level can be decreased and more precise results may be achieved. The fitness values of one SITL used in the LPF are demonstrated in Fig. 2 versus iterations. It is clear that the IWO converges to the optimum values found by IWO method under the used conditions in the last iteration, $iter_{max}$.

Table 1: The traditional low pass filter design parameters.

Element	Z_c (Ω)	θ_0 (rad)
C_1=C_4	20	0.31
C_2= C_3	20	0.61
L_1= L_3	120	0.62
L_2	120	0.75

Figure 3 shows the layout of the proposed LPF with step impedance transmission lines instead of the inductor and capacitor parts of the conventional LPF filter. The specifications of the step impedance parts of the filter are obtained from the IWO method. The calculated values have to be tuned because the discontinuities are not considered in the ABCD equations. We used Agilent Advance Design System (ADS) for tuning the final results shown in Table. 3. In this table, Z_1 and Z_2 are corresponding to the SITLs impedances and θ_1 and θ_2 demonstrate the electrical length of the SITL segments as shown in Fig. 1. It can be seen that the vertical lines are more compact than the horizontal lines. Figure 4 shows the fabricated low pass filter. We used one level folded transmission lines in the high impedance segment of the horizontal transmission lines. Also, the end segment position of the middle stubs (C_2 and C_3) is rotated to achieve more compactness. Notice that the effect of these changing is considered in the full wave simulation, which is done by using the method of moment (MoM) in ADS. The required space for the optimized designed filter (99.04 mm × 22.32 mm) is 30% of the traditional LPF required space (177.68 mm × 42.21 mm) that shows more than 70% compactness in the proposed structure.

Table 2: IWO parameter values for SITL optimization.

Symbols	Quantity	Value
N	Number of initial population	80
$iter_{max}$	Maximum number of iterations	72
D	Problem dimension	4
P_{max}	Maximum number of plant population	80
S_{max}	Maximum number of Seeds	10
S_{min}	Minimum number of Seeds	2
n	Nonlinear modulation index	3
$\sigma_{initial}$	Initial value of standard deviation	1
σ_{final}	final value of standard deviation	0.01
Z_1	Impedance of the sides	$10 < Z_1 < 180$
Z_2	Middle impedance	$10 < Z_2 < 180$
θ_1	Electrical length of the sides	$0 < \theta_1 < \theta_0/4$
θ_2	Electrical length of the middle lines	$0 < \theta_2 < \theta_0/4$

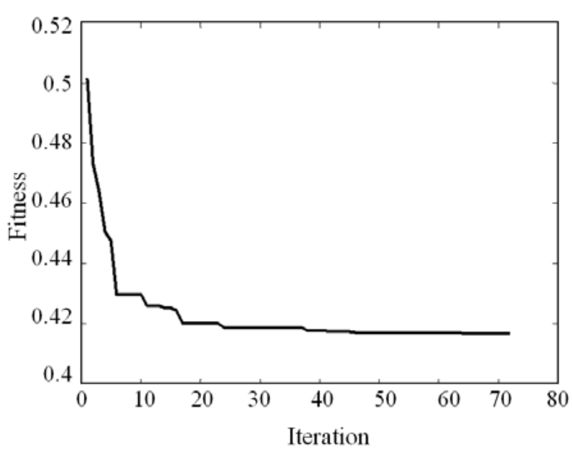

Fig. 2. The fitness function of a SITL versus iterations.

Table 3: Equivalent values for the proposed SITL LPF.

Elements	Z_1 (Ω)	Z_2 (Ω)	θ_1 (rad)	θ_2 (rad)
C_1=C_4	71	10	0.06	0.113
C_2= C_3	109.6	10	0.13	0.265
L_1= L_3	138.11	179.8	0.076	0.33
L_2	63.04	179.89	0.104	0.436

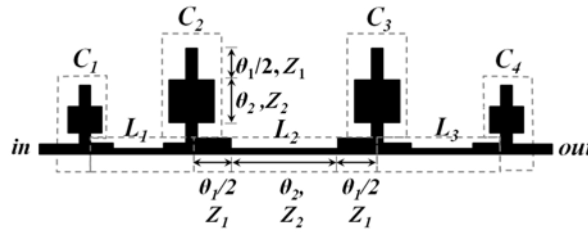

Fig. 3. Schematic of the compact filter.

Figure 5 shows the simulation and measurement results for the designed LPF. The measurements were taken by an Agilent network analyzer E5071C. There is a good agreement between the simulation and measurements results. Moreover, the results show that the first spurious response of the LPF is suppressed, which is achieved by using high Z- low Z lines in the filter configuration.

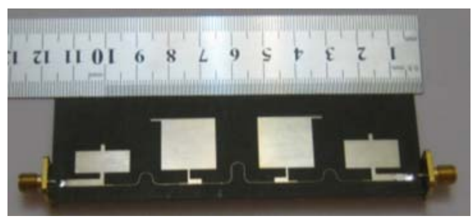

Fig. 4. Fabricated compact designed low pass filter.

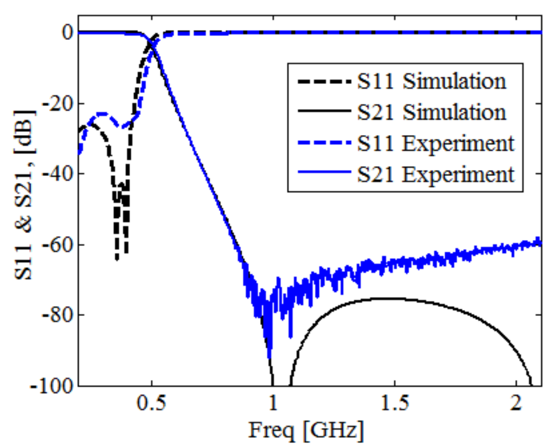

Fig. 5. The simulation and experiment results of the LPF.

V. CONCLUSION

The invasive weed optimization (IWO) approach has been applied to miniaturize the step impedance transmission lines (SITL). In the proposed method, the IWO technique attempts to replace the uniform microstrip lines of low pass filter by the most compact SITLs. The designed and fabricated LPF with optimized SITLs segments has more than 70% area reduction compare with the traditional one. The proposed method can be extended to compact the other microwave devices as well.

REFERENCES

[1] D. M. Pozar, *Microwave Engineering*, Second Edition, *Wiley*, 1998.

[2] J. Lin Li , J. Xin Chen, Q. Xue, J. P. Wang, W. Shao, and L. J. Xue, "Compact microstrip low pass filter based on defected ground structure and compensated microstrip line," *IEEE MTT-S International Microwave Symposium Digest*, pp. 1483-1486, 2005.

[3] C. C. Chen, C. Kuang, and C. Tzuang, "Synthetic quasi-TEM meandered transmission lines for compacted microwave integrated circuits," *IEEE Transaction on Microwave Theory and Techniques*, vol. 52, no. 6, pp. 1637-1647, 2004.

[4] Q. Xue, K. M. Shum, and C. H. Chan, "Novel 1-D microstrip PBG cells," *IEEE Microwave and Wireless Component Letters*, vol. 10, no. 10, pp. 403-405, 2000.

[5] F. R. Yang, Y. Qian, and T. Itoh, "A novel uniplanar compact PBG structure for filter and mixer applications," *IEEE MTT International Microwave Symposium Digest*, vol. 3, pp. 919-922, 1999.

[6] S. K. Gupta and K. J. Vinoy, "A compact defected ground microstrip device with photonic bandgap effects," *J. of Electromagn. Waves and Appl*., vol. 23, pp. 255-266, 2009.

[7] M. Challal, A. Boutejdar, M. Dehmas, A. Azrar, and A. Omar, "Compact microstrip low-pass filter design with ultra-wide reject band using a novel quarter-circle DGS shape," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 10, pp. 808-815, Oct. 2012.

[8] G. E. Al-Omair, S. F. Mahmoud, and A. S. Al-Zayed, "Lowpass and bandpass filter designs based on DGS with complementary split ring resonators," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 26, no. 11, pp. 907-914, Nov. 2011.

[9] M. Al Sharkawy, A. Boutejdar, F. Alhefnawi, and O. Luxor, "Improvement of compactness of lowpass/bandpass filter using a new electromagnetic coupled crescent defected ground structure resonators," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 7, pp. 570-577, July 2010.

[10] N. M. Garmjani and N. Komjani, "Improved microstrip folded tri-section stepped impedance resonator bandpass filter using defected ground structure," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 25, no. 11, pp. 975-983, Nov. 2010.

[11] Y. J. Sung, C. S. Ahn, and Y. -S. Kim, "Size reduction and harmonic suppression of rat race coupler hybrid coupler using defected ground structure," *IEEE Microwave and Wireless Component Letters*, vol. 14, no.1, pp. 7-9, 2004.

[12] X. H. Wang and B. Z. Wang, "Compact broadband dual-band bandpass filters using slotted ground structures," *Progress In Electromagnetics Research, PIER,* vol. 82, pp. 151-166, 2008.

[13] T. Yang, C. Liu, L. Yan, and K. Huang, "A compact dual-band power divider using planar artificial transmission lines for GSM/DCS applications," *Progress In Electromagnetics Research Letters,* vol. 10, pp. 185-191, 2009.

[14] P. Hajizade, H. R. Hassani, and S. H. Sedighy, "Compact quasi-Yagi antenna loaded with artificial transmission lines for RFID applications," *IEEE International Symposium on APS*, pp. 1-2, 2012.

[15] H. W. Liu, L. Y. Li, X. H. Li, and S. X. Wang, "Compact microstrip lowpass filter using asymmetric stepped-impedance hairpin resonator and slotted grounded plane," *J. of Electromagn. Waves and Appl*., vol. 22, pp. 1615-1622, 2008.

[16] M. H. Yang, J. Xu, Q. Zhao, L. Peng, and G. P. Li, "Compact broad stopband low pass filters using SIRS-loaded circular hairpin resonators," *Progress In Electromagnetics Research, PIER*, vol. 102, pp. 95-106, 2010.

[17] S. H. Sedighy and M. Khalaj-Amirhosseini, "Compact Wilkinson power divider using stepped impedance transmission lines," *J. of Electromagnetics Waves and Appl*., vol. 25, pp.1773-1782, 2011.

[18] S. H. Sedighy, A. R. Mallahzadeh, M. Soleimani, and J. Rashed-Mohassel, "Optimization of printed Yagi antenna using invasive weed optimization (IWO)," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 1275-1278, 2010.

[19] A. R. Mehrabian and C. Lucas, "A novel numerical optimization algorithm inspired from weed colonization," *Ecol. Inform*., vol. 1, pp. 355-366, 2006.

[20] S. Karimkashi and A. Kishk, "Invasive weed optimization and its features in electromagnetics," *IEEE Transaction on Antennas and Propagation*, vol. 58, no. 4, pp. 1269-1278, 2010.

[21] A. R. Mallahzadeh, S. Es'haghi, and H. R. Hassani, "Compact U-array MIMO antenna designs using IWO algorithm," *Int. J. RF Microw. Comput*., vol. 15, no. 5, pp. 568-576, 2009.

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