Ultrawideband Tapered Balun Design with Boundary Curve Interpolation and Genetic Algorithms

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Introduction

Wideband balun design has been a focus of active research for many years. First baluns [1] appeared as a solution to the junction between a bifilar transmission line (balanced line) and a coaxial line(unbalanced). Several kind of baluns have appeared applied to microwave applications, such as microstrip circuits, microwave and monolithic microwave integrated circuits (MIC's and MMIC's).

This paper presents a new Microstrip line (MS unbalanced line) to Parallel-strip transmission line (PS balanced line) balun design [2,3]. The original contribution consists in using two different interpolation functions and Genetic Algorithms (GA) [4] as optimization method.

Balun Geometry and Boundary Curve Interpolation Method (BCIM)

A.Transition Configuration

Fig.1 shows a printed transition between a MS and a PS transmission line. It comprises of two different thin conductor stripes printed in opposite sides on a substrate. The bottom side will perform the transition between the MS ground plane and the lower strip in the PS, while the upper strip will work in a similar way as in MS and PS, providing if necessary, impedance matching properties.

The geometrical parameters that define the model are the balun length L,the MS line width W_1, the PS line width,W_2 and the *boundary curve function* $\xi(x)$, which defines the way the ground plane becomes the bottom parallel strip.

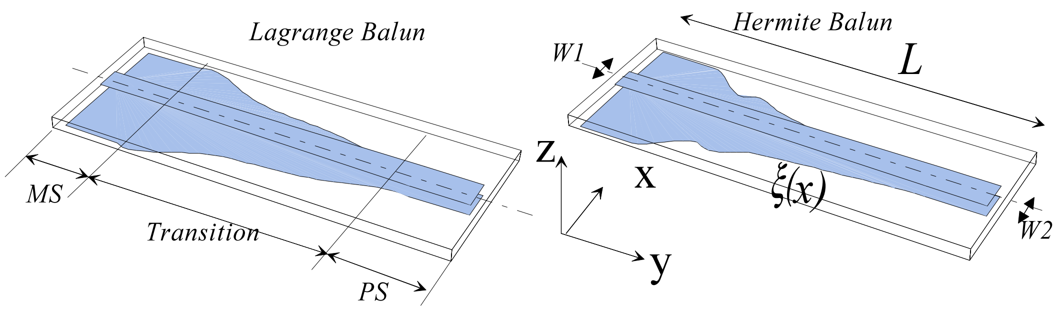

Figure 1: Best individual MS-PS balun structure obtained with GA.

B. Boundary Curve Interpolation Method for balun geometry generation

In order to get good performances regarding the return and insertion losses in transitions between different transmission lines, the tapered section method is classically one of the most used [5]. The physical idea consists of managing smooth geometrical variations between the geometrical structure which maps the initial transmission line and that which maps the final transmission line. Those smooth variations may be accomplished through the Boundary Curve Interpolation method (BCIM). This is based on the use of interpolating functions which fulfill the geometrical constrains to satisfy some electrical requirements (for instance,input impedance). Two interpolation schema will be tried:

i)*Lagrange Interpolation.*Let [0,L] the interval and N+1 points ,the boundary curve function will be:

$$\{(x_0, y_0), (x_1, y_1) \ldots (x_N, y_N)\}, \xi(x) = a_0 + a_1 x + a_2 x^2 + a + \ldots + a_n x^n$$

ii)*Hermite Interpolation or Osculating Interpolation.* Considering the same interval, not only the points but the first derivatives are specified. A cubic polynomial between two points is built.

$$\{(x_0, y_0), \ldots, (x_N, y_N), (x_0, \xi'(x_0)), \ldots, (x_N, \xi'(x_N))\}, \xi_i(x) = H_0 + H_1 x + H_2 x^2 + H_3 x^3$$

It will be shown that Hermite polynomials, as expected , give better performance since they allow to build a larger variety of curves than a rigid Lagrange interpolation. Although both curves belong to $C^1[0, L]$ class curves, the Lagrange polynomials fix the derivatives while in Hermite method may be modified, giving an extra freedom.

Genetic Algorithm simulation

A GA optimization will be applied as a procedure to work out the boundary curves,using the *interpolants*,i.e. the points and/or derivatives, and a *fitness function* which will impose a desired constrain.Two baluns were synthesized, one which uses Legendre interpolation(designated as LB) of 7^{th} order and one using Hermite interpolation (called HB) using three points and three first derivatives as genes. The chosen substrate was FR4, with parameters $H = 1.6mm, \epsilon_r = 4.6, tan\delta = 0.02$. Input and output impedances were selected to be 50 Ω,imposing edge strip geometry. The ground plane width was chosen to be 20mm,so as the input transmission line is considered as MS line. The balun length L was selected to be $L = \lambda_g/4$ being λ_g the guide wavelength at 1 GHz (lower frequency). Table 1. summarizes the parameters of LB and HB baluns.

Table 1: Genetic variables used in optimization

Balun type	LB				HB					
Parameter	x_i	$\xi(x_i)$	x_{opt}	ξ_{opt}	x_i	$\xi(x_i)$	$\xi_i'(x_i)$	x_{opt}	ξ_{opt}	ξ_{opt}'
Value	0	10	0	10	0	10	0	0	10	0
	x_1	y_1	8	8.02	x_1	y_1	$\xi'(x_1)$	8.16	6.23	0.69
	x_2	y_2	11.93	6.5	x_2	y_2	$\xi'(x_2)$	14.11	4.68	-0.22
	x_3	y_3	17.88	5.63	x_3	y_3	$\xi'(x_3)$	25.34	3.28	-0.08
	x_4	y_4	22.36	5.27	–	–	–	–	–	–
	x_5	y_5	30.45	3.33	–	–	–	–	–	–
	37.5	2.2	37.5	2.2	37.5	2.2	0	37.5	2.2	0

A simple binary type GA was used and each gene was codified using 16bits, and the population size was chosen to be 25. The GA was let to evolve during 30 generations with a probability of crossover of 0.65 and a probability of mutation of 0.01. Additionally, a simple generational replacement strategy was implemented. A distance-based fitness function was used to reach the optimum value. A constrain of $S_{11}^{opt} = -25dB$ in the frequency band from 1 GHz to 11 GHz,i.e., an UWB frequency behavior was codified by the function:

$$Fitness = -10\log_{10}\left[\sum_{i=1}^{11}\left(|S_{11}(f_i)| - \left|S_{11}^{opt}\right|\right)^2\right], f_i = 1 \ldots 11GHz$$

Fig 2. shows the results of GA in HB and LB cases, showing an improvement when the HB case is considered.

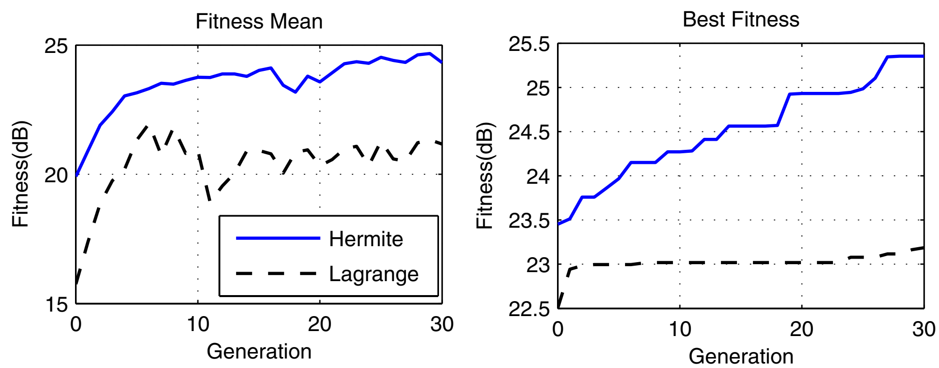

Figure 2: GA performances of LB optimization vs HB optimization.

Circuit and Electromagnetic Performances of the balun

A.Scattering Parameters optimal solution

Fig.3 shows the S-parameters obtained from the IE3D MoM solver, where port 1 refers to the MS line and port 2 refers to the PS line in both cases, HB and LB.

B.Balance analysis from the Average Current Density $< J_s >$

Despite Scattering parameters have been presented, it is important to show a phase difference measurement in the PS. The fact of a good S-parameter response does not guarantee a good 180 degree phase balance. If differential ports are used for solving the structure, it is not possible to extract directly this phase difference, that depends strongly on the total balun length. Even so, it is still possible to get this measurement, by performing a current analysis. When perfect 180 degree phase difference is achieved, if $\vec{J}_{su}$ and $\vec{J}_{sd}$ are the average current density on the top and bottom strip, then:

$$\| < \vec{J} >_{su} \| = \| < \vec{J} >_{sd} \| \text{ on PS edge}$$

If a quasi-TEM propagation mode and y-propagation direction are assumed then:

$$E_y(x,z) \approx 0, H_y(x,z) \approx 0 \longrightarrow < J_s(y) > \approx \frac{1}{W(y)} \int_{-W(y)/2}^{W(y)/2} J_s(x,z)dx$$

Fig.4 introduces this computation for 1GHz, which will be the worst possible frequency, and 2 GHz to illustrate a situation in which the balun will work.

Conclusions

Using BCIM and GA optimization, a way of building tapered balun geometries has been proposed, leading to a printed balun of excellent electrical performances. This method is very useful, since many structures may be analyzed, that is, the search space for looking for the best individual using evolutionary algorithms is very wide. It is showed that Hermite polynomials provide a more efficient structure, and VSWR below 1.25 in a wide frequency band and insertion losses below 2 dB in FR4 substrate are obtained. In addition, a novel method for detecting unbalances based on average current density was introduced, showing the convergence up to the balanced signals.

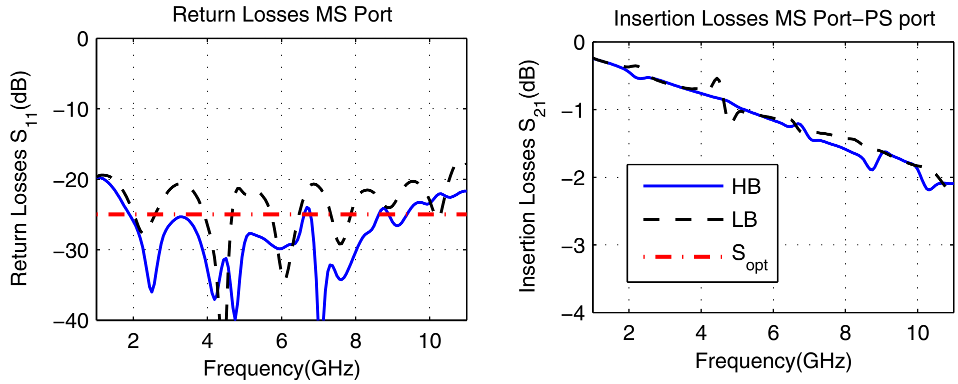

Figure 3: S parameters of Hermite and Lagrange Baluns.

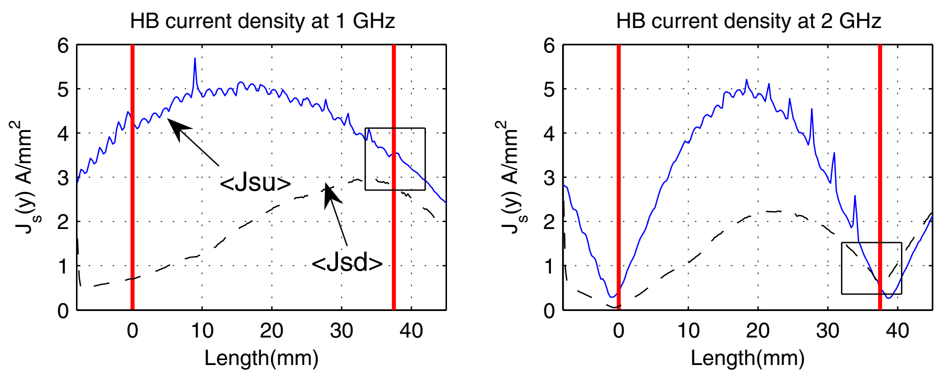

Figure 4: $< J_s(y) >$, showing the balanced and unbalanced situation.

Acknowledgements

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