High Power and Ultra-wideband Balun with Multiphysics Modeling

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***Abstract*—This document presents the development of a high power and low loss balun that operates over a 0.1-1.7 GHz bandwidth. The proposed balun employs a novel compensated circuit of a semi-rigid coaxial cable and an on-chip inductor on a modified defected ground ceramic board to allow high power and ultra-wide bandwidth performance. The experimental results show the balun achieves an insertion loss of less than 1 dB as well as amplitude and phase imbalance are within 0.5 dB and 5°, respectively. Multiphysics simulation and high power measurement demonstrate that the balun handles 600 W and above at 1 GHz.**

***Index Terms*— Transmission line balun, wide bandwidth balun, defected ground structure, semi-rig coaxial, Multiphysics**

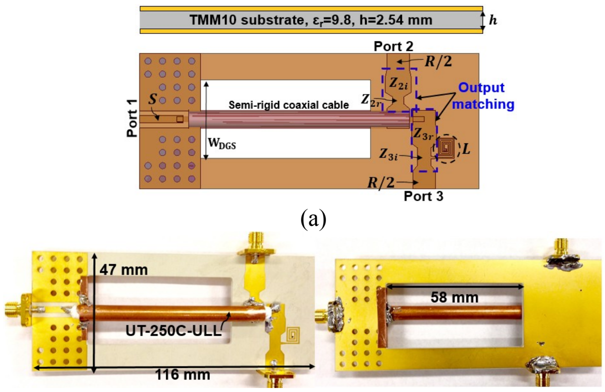
I. INTRODUCTION

HIGH power balanced radio frequency (RF) components and circuits require a broadband balun to convert unbalanced signals into balanced ones and vice versa. Particular frequency band is below 2 GHz because current commercial ferrite baluns are lossy, bulky and also handle low-power. To address these challenges, the research project develops a ferriteless compact balun integrated with artificial transmission line structures [1-5]. The letter demonstrates comprehensive Multiphysics analyses which determine power handling capability of the balun. Finally, electrical and high power experimental results verify that the balun can handle more than 600 W at 1 GHz without any structural breakdowns [6]. The results of this research will establish a new class of high performance passive element circuits using novel artificial transmission line structures incorporated with Multiphysics modeling approaches.

II. PROJECT OUTCOMES

A. Balun Structure and Principle

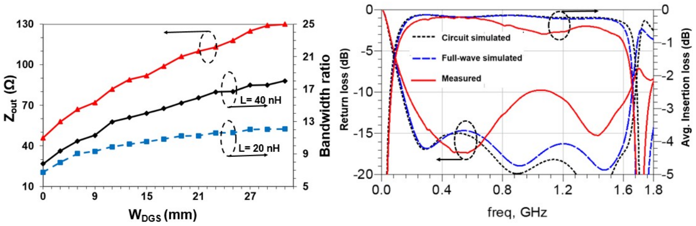
Fig. 1 shows the proposed coaxial balun and its prototype. This consists of a semi-rigid coaxial structure sitting on a single layer ceramic board with a modified rectangular-shaped defected ground substrate (DGS). The modified DGS width is W_{DGS}. The balun balanced ports (Port 2 and 3) include inter-matching impedances, Z_{2r}, Z_{2i} and Z_{3r} Z_{3i} for Port 2 and 3, respectively and a single on-chip spiral inductor L at Port 3 output. The unbalanced port and balanced port impedances are chosen as 50 Ω and 25 Ω, respectively. The characteristic impedance of inner conductor of the coax and the parasitic TL are Z_o and Z_{out}, respectively. Here, Z_{out} must be large compared the balanced port impedance S to have no power reflected to unbalanced port in order to achieve the widest bandwidth.



(a)

(b)

Fig. 1. (a) Cross section and top view of the ferriteless balun and (b) The balun prototype.



(a) (b)

Fig. 2. (a) Extracted characteristic impedance Z_{out} and bandwidth ratio of the proposed balun. (b) Measured return loss and average insertion loss.

To achieve high Z_{out}, the letter uses a modified defected ground structure (MDGS) implementation. The MDGS removes both the dielectric substrate and metal ground underneath the coaxial line. Variations of the DGS width changes the characteristic impedance extracted from two-port device simulation using ANSYS [8]. As can be seen in Fig. 2, Z_{out} and bandwidth ratio (*BWR*) increase proportionally to the defected area width and then saturates when W_{DGS}>27 mm. The return loss of balun is better than 10 dB from 0.1 GHz to beyond 1.7 GHz. The balun achieves an average insertion loss of 1 dB from 0.1 GHz to 1.7 GHz.

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B. Multiphysics modeling and high power measurement

The research performs a comprehensive Multiphysics ANSYS analysis to address average power handling capability (APHC), where it is assumed that a very high signal power (500-1000 W) is applied to the circuit and the electro-thermal-mechanical coupling is analyzed in order to determine the temperature margin, local hot spot and thermal stress of the circuit as a function of the input signal power. In a planar circuit, conductive and dielectric losses defined as internal heat which limits maximum working input power of the circuit. Also in the balun structure, it should be noted that glass transition temperature of the TMM ceramic substrate and cable dielectric are 1200°C and 262°C respectively [7-8]. They will determine the peak APHC.

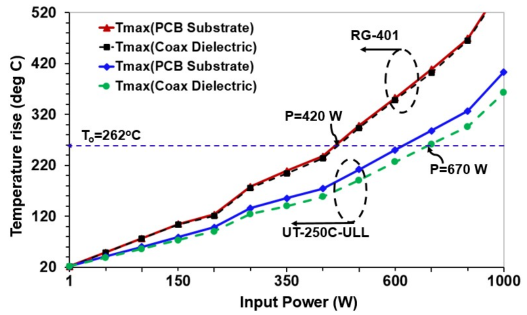


Fig. 3. Temperature rise profile on the substrate and coaxial dielectric of the balun using two semi-rigid coaxial cables.

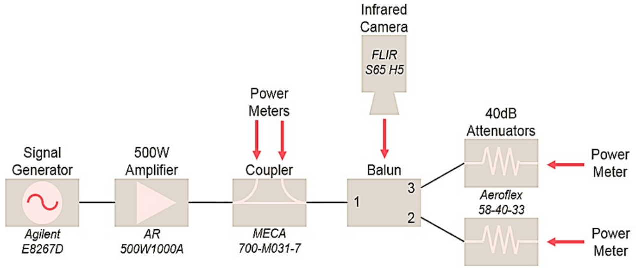
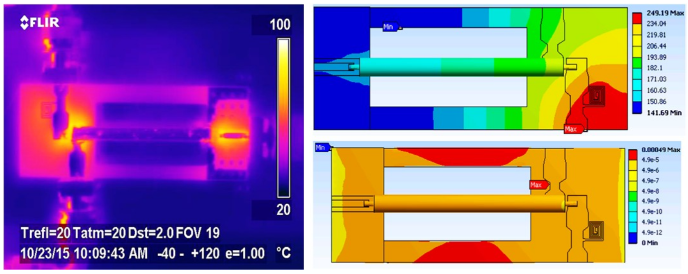


Fig. 4. High power test block diagram of the coaxial balun.

Fig. 3 depicts maximum temperature rise in the substrate and coaxial dielectric in case of using a semi-rigid coax (RG-401) with temperature-dependent Teflon and a low-loss coax cables (UT-250C-ULL). For the former cable, the balun can operate up to 400 W and then be malfunctioned above 400 W because Teflon can transit into glass at T_o=262°C. For the low-loss cable, the balun can perform a normal operation up to 650 W because dielectric material of the coax cable is low loss and stable with temperature.

Fig. 4 shows block diagram of high power measurement of the balun test fixture module using N-type connectors. Fig. 5 shows the measured temperature distributions in case of 500 W input power at 1 GHz, which is in agreement with thermal analysis on the balun. Also, a structural analysis shows a maximum deformation of 49 µm along the balun sides, which will not affect the low frequency balun performance over its bandwidth.



(a) (b)

Fig. 5. (a) Captured infrared image result. (b) Thermal and structural analysis on the ferritless balun.

III. CAREER PLAN AND FELLOWSHIP IMPACT

I would like to thank the IEEE Microwave Theory and Techniques Society for granting me the 2016 IEEE Graduate Fellowship Award. This has motivated me to continue my research in Microwave engineering to fulfill my career goals. Given the fellowship, I was able to reach out industrial vendors, to fabricate circuit and test-fixture prototypes for high power measurement. This financial support also helped me to attend the International Microwave Symposium 2016 where I presented and reviewed the research project with many professionals during technical sections and interacted with industrial exhibitors as well.

My goals are to continue expand my research in the field of RF/Microwave engineering, focusing on signal integrity, high efficiency wireless power transfer and development of miniaturized, high performance circuits using multifunctional composites and novel artificial structures. By far, I plan for industrial career where I will be able to bring engineering ideas to practical productions in market.

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