Improved compaction of multilayer MMIC/MCM baluns using lumped element compensation

R.H. Jansen, J. Jotzo and M. Engels

RWTH Aachen, Dept. of El. Engineering, ITHE, Kopernikusstr. 16,
D-52074 Aachen, Germany

Abstract

A novel lumped impedance matched type of Marchand balun in MMIC/MCM technology is described which is compact enough even for the low-GHz frequency range. Broadband performance and balance of this component are sufficient for the use in many wireless applications.

Summary

Monolithic and hybrid broadband compensated baluns of the Marchand type [1], [2] feature excellent electrical performance, but are quite space consuming in their original form except if operating frequencies move up into the millimeter-wave region. Very recently, however, compact balun structures have been demonstrated together with a suitable design procedure [3] which are essentially wound-up transmission line transformers (TLTs) using a second wound-up TL-structure for compensation, thus resulting in excellent broadband balance [4]. This latter approach, for example, allows to design cost-saving balun structures in MCM technology on thick silicon [5] even for wireless communication applications in the low-end GHz region [6]. A simple schematic visualizing this approach is depicted in Fig. 1(a) while the simplified top view of a respective balun component on silicon is given in Fig. 1(b).

The structure of Fig. 1(b) uses three metal levels (M1...M3) and two polyimide separation layers in between to realize the necessary broadside coupled (stacked) strips and required interconnections. It sits on a thick silicon substrate in a groundplane opening of suitable size. The space consumption of such a 1.9 GHz balun with 1:4 impedance transformation is about $2.5mm^2$, for example.

This paper starts from the fact that many wireless communication subsystems do not need the full potential of broad bandwidth and excellent balance to

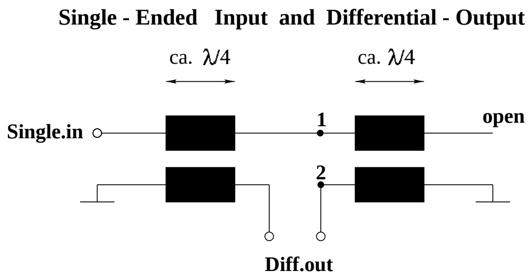

Fig. 1a: Schematic of compensated TLT-balun

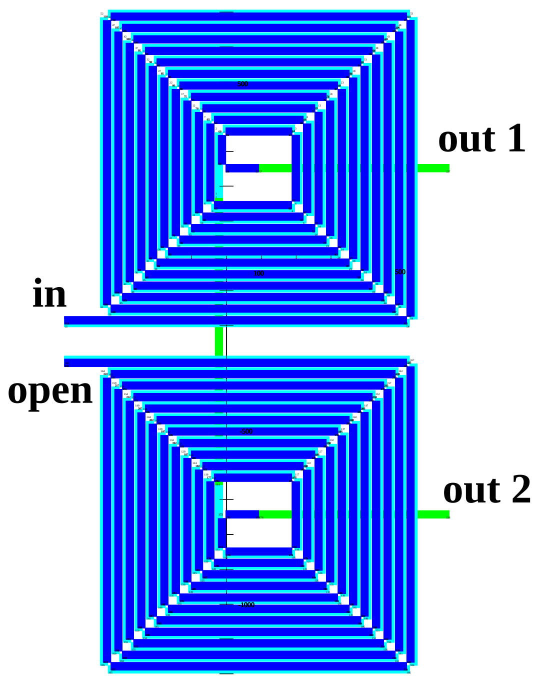

Fig. 1b: Top view of layout in MCM technology (simplified)

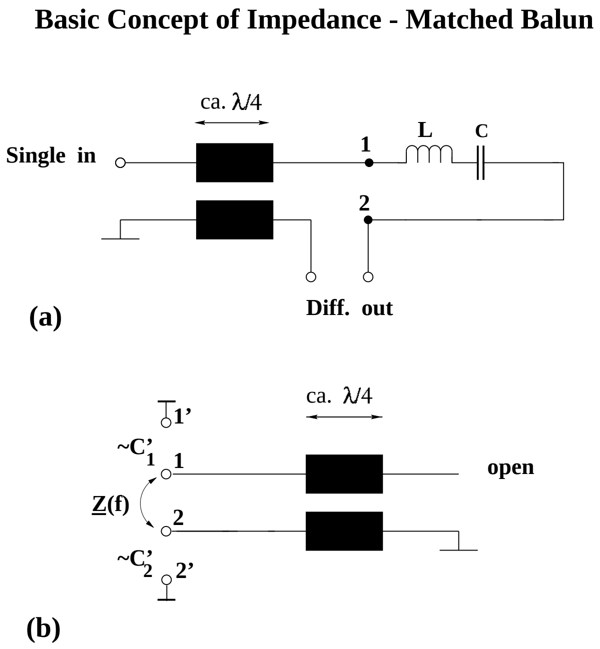

Fig. 2: Balun with 1st order impedance compensation (a), Schematic and closer view of electrical situation (b)

a degree that the type of TLT-balun of Fig. 1 offers. However, simply removing the open-ended compensation line (stacked strips) in Fig. 1(b) and thus halving the space requirements leads to poor electrical performance, particularly to poor balance of the output signal [4]. The idea is, therefore, to replace the TL- type compensation structure by a lumped and much more compact impedance representation $\underline{Z}$(f) as indicated in Fig. 2(a), with $\underline{Z}$(f) being an LC series combination to the first approximation (input impedance seen between nodes 1 and 2 of open-ended stacked strips). This is considered in more detail in Fig. 2(b), where the fact is taken into account that the signal voltages on the stacked strips and the node voltages V1, V2 have to be referenced to the ground plane metal on the silicon substrate (M1) opened beneath the component but present around at close lateral distance. As indicated in Fig. 2(b), the stacked strips as well as the physical LC realisation have a stray field to ground which to a first approximation is represented here by capacitance values C_1' and C_2' (usually small).

Note, that the substitution of the structure of Fig. 2(b) is not a single impedance, but a π- or T- equivalent circuit with nodes 1, 2 and ground. Accordingly, $\underline{Z}(f) = Z_{11}+Z_{22}-2Z_{12}$ applies when formulating $\underline{Z}$(f) in terms of two-port impedance elements and takes into account all associated impedance parameters 11, 22 and 12.

In order to look into the details of the impedance representation required, the same field- theory based quasi-TEM multilayer simulation tool already applied in [3], [4], with an earlier version described in [7], [8] has been used. This tool has been verified repeatedly in the past by comparisons with measurements performed on similar components and with 2.5D EM results generated by another commercial simulator [7], [8]. Therefore, it can be considered as a reliable basis for the investigation conducted here and was used to compute the impedance $\underline{Z}$(f) as seen into the open-ended TL-type spiral-shaped compensation structure of Fig. 1(b). It was also used to design the lumped element LC compensation structure visible in Fig. 3(a) in such a way as to obtain a good fit with $\underline{Z}$(f). This is illustrated in Fig. 3(b), with the solid curve identifying the LC equivalent while the dashed curve represents the electrical performance (impedance) of the original TL-type spiral. The inductance value L needed here is about 8.4nH and the required capacitance is about 1.3 pF. The physical realization in the respective MCM silicon process [5] is shown in Fig. 3(a). The capacitor uses in inorganic dielectric and has square dimensions of 100 μm. The inductor track width has been chosen as small as 5 μm in order to minimize space consumption. For reasons of clarity, Fig. 3(c) shows a vertically expanded view of the structure detailing the 3 metal levels and interconnnects.

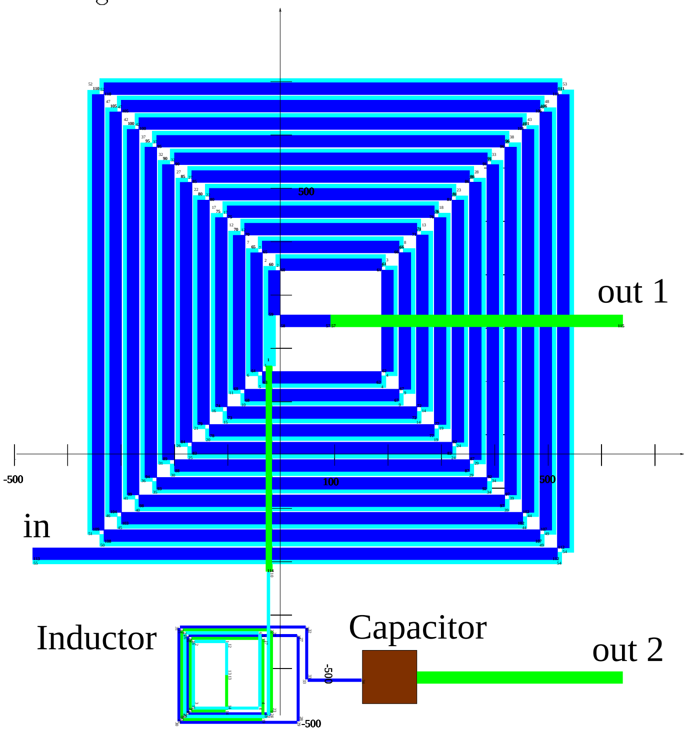

Fig. 3(a): Layout of LC-compensated balun in MCM technology (simplified)

0-7803-4603-6/97/$5.00 (c) IEEE

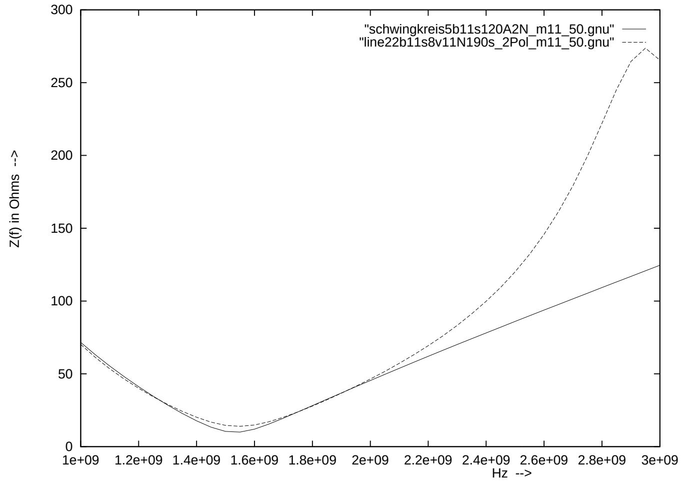

Fig. 3(b): First-order impedance fit of LC-structure vs. TL-structure (dashed)

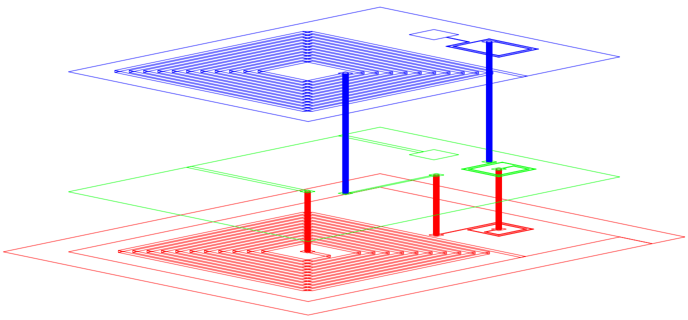

Fig. 3(c): Vertically expanded view of the LC-compensated balun

The impedance matched balun component of Fig. 3(a) has been layed out for processing at GEC Plessey Semiconductors early 10/96 [6].

Note, that the further compaction (space reduction) obtained by the LC-version of the balun is about 35% compared to the layout of Fig. 1(b). The LC series combination used so far fits the series resonance of $\underline{Z}$(f) visible in Fig. 3(b) at f = 1.55GHz quite well, but is not suited to simultaneously approximate the additional parallel resonance seen at 2.95GHz. However, this can be achieved with virtually no further space requirements by adding another smaller capacitor C_{par} in parallel to the LC series connection, which in the physical realization has a size of about 40 μm x 40 μm only and is placed between the fundamental TLT structure and the series C element. With L, C and C_{par} applied, a very good fit of $\underline{Z}$(f) in Fig. 3(b) - the dashed curve - is obtained for the full range of 1 - 3GHz relevant here.

The electrical performance of the original 1.9GHz balun of Fig. 1(b) and of the impedance matched balun shown in Fig 3(a) (as well as of the further modification using C_{par} as outlined) is given in Fig. 4(a), (b) and (c). Besides the previous verification of the quasi-TEM multilayer tool [7], [8] used to generate these simulation results, further evidence of the correctness of these results was produced by independent computations made with the commercial package LINMIC+/N [9] which will be included in the presentation. Fig. 4(a) shows the input return loss of the three balun versions discussed here, original of Fig. 1(b) - dashed curve, impedance matched (IM) type of Fig. 3(a) - solid curve, and version using additional C_{par} capacitor - dotted line. The performance of these three versions is very close up to 3.0GHz. The output return loss results are also close and therefore not shown here. The transmission behaviour illustrated in Fig. 4(b) reveals similar agreement, however, only up to about 2.8GHz. It is interesting to see that the original balun of Fig. 1(b) has better performance (dashed) at the low frequency end, while the IM typ version (solid) of Fig. 3(a) extends favourably up to 3GHz. Finally, the suppression of the common mode output signal (as a measure of good balance) is shown in Fig. 4(c). The excellent broadband quality of the TL-compensated balun (dashed) of Fig. 1(b) outperforms clearly the IM type versions. However, more than 20dB of common mode suppression are obtained for the compacted lumped element versions (solid, dotted) in the range of 0.8 - 2.8GHz, which is well sufficient for many wireless applications.

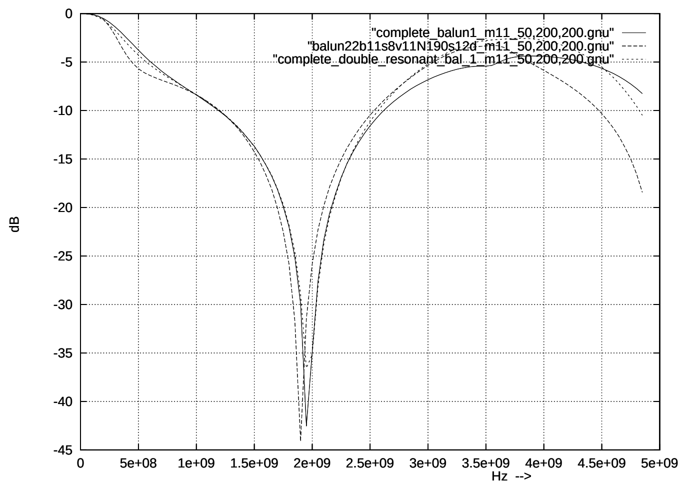

Fig. 4(a): Input return loss of 1(b) version — — — , of 3(a) IM type ———, and of 3 (a) version with C_{par} added ······

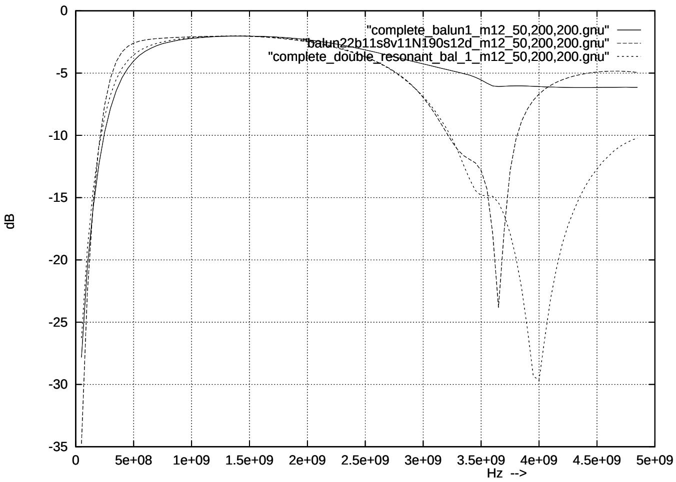

Fig. 4(b): Transmission loss of the three versions in comparison

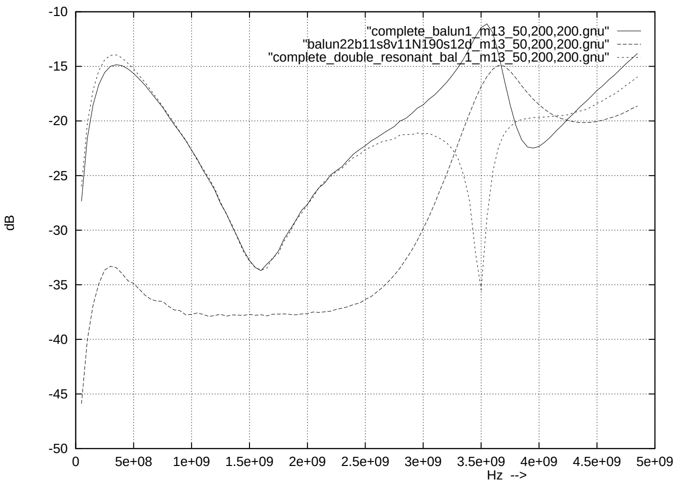

Fig. 4(c): Common mode suppression of the three versions in comparison

Conclusion Marchand baluns are a very good solution for broadband impedance transformation. The impedance-matched balun presented here has similar transmission performance, but needs only 65% of the substrate area of an already compacted spiral-type Marchand balun. The main drawback of the impedance matched version is the higher common mode output signal, but this is still sufficiently well suppressed for many wireless applications.

References

[1] N. Marchand: *Transmission-line conversion transformers* , Electronics, vol. 17, pages 142-145, 1944.

[2] A.M. Pavio and A. Kikel: *A monolithic or hybrid broadband compensated balun,* IEEE MTT-S Int. Microwave Symp. Digest, pages 483-486, Dallas/TX, USA, 1990.

[3] M. Engels and R.H. Jansen: *Design of Integrated Compensated Baluns,* Microwave and Optical Technology Letters, Wiley-Interscience, New York, accepted for publication October 1996.

[4] M. Engels and R.H. Jansen: *A novel compact balun structure for multilayer MMICs,* Proc. 26th European Microwave Conf., pages 692-696, Prague, Czech Republic, September 1996.

[5] R.G. Arnold and D.J Pedder: *Microwave characterization of microstrip lines and spiral inductors in MCM-D technology,* IEEE Trans. on Components, Hybrids, and Manufacturing Technology, vol. CHMT-15, no. 6, pages 1038-1045, December 1992.

[6] *GPS Project Report 8/1996* Jansen Microwave, Aachen, Germany, September 1996.

[7] M. Engels and R.H. Jansen: *A hybrid technique for modeling stacked MMIC components including 3D capacitance and conducter thickness effects,* 1994 Asia- Pacific Microwave Conference Proc., pages 515-518, 1994.

[8] M. Engels, R.H. Jansen, W. Daumann, R.M. Bertenburg and F.J. Tegude: *Design methodology, measurement and application of MMIC transmission line transformers,* IEEE MTT-S Int. Microwave Symp. Digest, pages 1635-1638, Orlando/FL, USA, 1995.

[9] *LINMIC+/N Software and Users Manual,* Version 4.0, Jansen Microwave, Aachen, Germany, October 1995.

0-7803-4603-6/97/$5.00 (c) IEEE