Design of Test Modules for the Characterization of SAW Duplexer Inserts by Measurement

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***Abstract*— Due to the growing demand for miniaturization and functionality of modern mobile W-CDMA terminals, current developments for integrating SAW or FBAR duplexers into subsystems such as LTCC front-end modules by means of duplexer inserts have been reported recently. We will present the first approach to our knowledge to design test modules for the characterization of SAW duplexer inserts by measurement.**

The main goal is to characterize the duplexer insert in the environment of an LTCC module without the influence of the other active or passive, mounted or integrated components of the module. This can be achieved by replacing all components, including all metal structures of the LTCC module, with the exception of the duplexer insert, by electrically neutral connections. They have to be well designed for high isolation between the signal paths and have to be optimized for good matching between the PCB and the module. This was realized by using a modified stripline with a slotted ground, which offers both the required high isolation and the required impedance of 50 Ω. Additionally, the PCB-module transition was designed carefully for low reflections. We call the combination of duplexer inserts and neutral connections a test module.

By focusing on the design approach of the neutral connection, we will present first samples of test modules with duplexer inserts for W-CDMA1900.

I. Introduction

The trend of miniaturization and integration in all fields of technology is still unbroken. It leads to smaller, more functional, and cheaper components. For mobile communication miniaturization and integration means more compact mobile terminals, which not only offer voice function, but also support many multimedia services such as SMS, MMS, eMail, MP3, and for packet switching GPRS, EDGE, and so on. Furthermore, to be suited for a large clientele, they have to support the current mobile standards 2G and 3G with their different frequency bands. Additionally, several short range data transmission standards like IrDA and Bluetooth are also integrated. It is only possible to concentrate this amount of functionality in the known small mobile terminals by means of integrating the key components being subsystems to achieve a higher integrated system, so called System-in-Package (SiP), see Fig. 1a.

Considering the air-terminal interface, design engineers and manufactures of RF-front ends are attempting to integrate the essential components such as power amplifiers, LNAs, mixers, switches, ESD protection, SAW or FBAR filter components, combined with several passive components, e.g., for matching, on as few modules as possible, ideally on one.

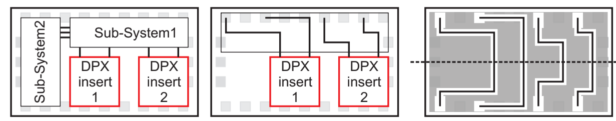


Fig. 1. Three exemplary modules: (left) front-end module with several subsystems including two duplexer inserts, (middle) test module with two duplexer inserts and neutral connections, and (right) module with symmetrical through connection.

II. Design of Test Modules tor the Measurement of Duplexer Inserts

Testing complex RF front-end modules is a difficult task, especially when trouble shooting malfunction. One possible approach is to split such a complex system in its subsystems and test them individually without the influence of the other parts. It is tightly connected to the specification of interfaces between the subsystems. The operation of the subsystem has to be tested in reference to its interface. Applying to modules with duplexer inserts requires the removal of all subsystems which do not belong to the duplexer inserts. In order to make the necessary electrical connection, transmission lines from the inter-module interface of the duplexer insert to the footprint are needed, see Fig. 1b. The electrical connection should be neither degrading nor improving the performance of the duplexer insert, it has to be an electrically neutral connection and therefore should be designed carefully. We call the combination of one or more duplexer inserts with electrically neutral connections a test module. The resulting module size can be arbitrary, but choosing the same size as the front-end module has advantages. In this case, the test module can be manufactured with the front-end modules simultaneously. Thus, manufacturing variations have the same impact on the performance of the duplexer inserts in both module types.

A. Duplexer Inserts in Module Environment

The duplexer insert is a new concept for integrating duplexing functionality into a module [1]. This can be achieved by separating a stand-alone duplexer into two parts. The first

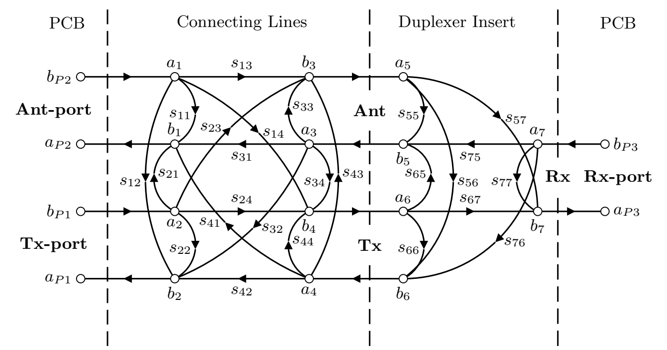


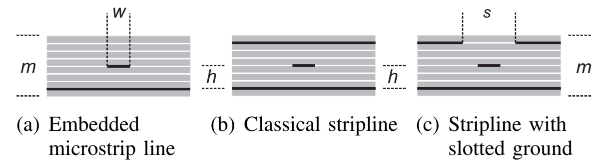
Fig. 2. Signal flow graph of a duplexer insert with lines connecting the Tx and Ant of the duplexer insert to the Tx-port and Ant-port of the module.

part contains the acoustic die for the filtering function. It can be mounted as bare die or with a protective HTCC housing on the module. The second part contains the required phase shifting element and additional inductive/capacitive elements to improve duplexer performance.

The main benefit of this concept is to reduce the overall height of the module in comparison with a module with standalone duplexer soldered on the top. But there are also arising challenges in the duplexer insert concept. Firstly, due to the limited space in the module there are strong mutual couplings between the duplexer insert and other structures with the possible consequences of deterioration of attenuation or isolation. Secondly, the duplexer insert has to fit in the layer stack predefined by the host-module.

B. Electrically Neutral Connections

Fig. 2 shows a simplified signal flow graph [2] for a single-ended duplexer insert. Tx and antenna (Ant) of the duplexer insert are connected via lines to the Tx-port and Ant-port of the test module . It is assumed that cross-talk between the lines and the Rx-port can be neglected because of the geometrical arrangement. In addition, perfect matching between the DUT, i.e., test module with duplexer insert and connecting lines, soldered on a neutral test PCB, and a well calibrated NWA is assumed. Referring Fig. 2 it becomes obvious, that the cross-talk branches with the scattering parameters s_{12}, s_{21}, s_{23}, s_{32}, s_{34}, s_{43}, s_{14}, s_{41} between the connecting lines, and the reflection branches with the scattering parameter s_{11}, s_{22}, s_{33}, and s_{44} of the connection lines impact the measured performance of the duplexer insert. Thus, e.g., reflections at the Tx-port, which can mask the reflection coefficient s_{66}, and cross-talk on the branch with the scattering parameter s_{23}, which is in parallel to the Tx-filter, make the precise characterization of the duplexer insert difficult. Thus, it appears that the type of line which is used as an electrically neutral connections has to offer high isolation in the cross-talk paths and the required impedance of 50 Ω. Additionally, the PCB-module transition should be matched. An embedded microstrip transmission line, see Fig. 3a, would be the first choice. Apparently, the reachable isolation level is lower than in case of a classical stripline, Fig. 3b. It would offer



(a) Embedded microstrip line (b) Classical stripline (c) Stripline with slotted ground

Fig. 3. Cross-section of types of transmission lines.

the required isolation level, but especially in low profile modules the characteristic impedance would be lower than 50 Ω, because of the limits of minimal line width in state-of-the-art LTCC processes. Illustrating this, the theoretically achievable characteristic impedances of microstrip lines and striplines with the typical width of 100 μm or 75 μm by varying the height h of the transmission line are shown in Fig. 4. These values are calculated for a fictive module which consists of 8 layers of LTCC, each 50 μm thick, with a typical relative permittivity of $\epsilon_r = 8$. The resulting total module height m is 400 μm. The thickness of the transmission line is assumed to be 10 μm. The height h of the transmission lines is referenced from the top side of the bottom ground plane to the bottom side of the line. The bottom ground layer located between the first and second layer counted from the bottom and the upper ground plane for the striplines is located in the seventh and eighth layer, which are shown in Fig. 3. Referring to Fig. 4, a characteristic impedance of 50 Ω for a stripline in a module with the typical height of 400 μm is not reachable. Additionally, by using fixed line widths the height h can only be varied in discrete steps in respect to the layer thickness and therefore not every intermediate value of the characteristic impedance can be reached. For the calculation the formulas for off-center stripline and embedded microstrip line were used [3]. To avoid these restrictions of types of transmission line mentioned above, we have used a modified stripline, which offers simultaneously the needed high isolation between the lines and the characteristic impedance of 50 Ω in low profile modules. Slotting one of the ground planes of the stripline, preferably the upper one, enables to obtain higher impedances, because of the lower capacitive load of the transmission line. The cross-section is

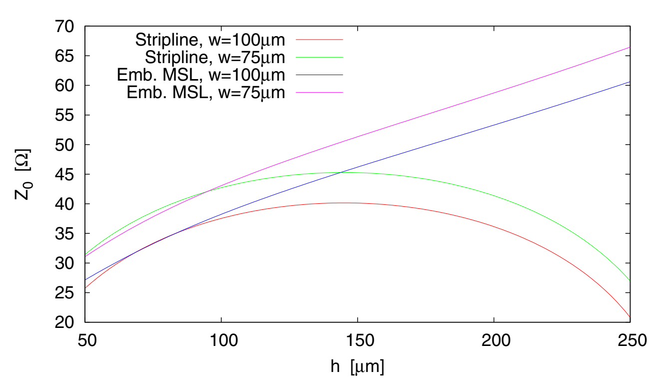


Fig. 4. Reachable characteristic impedances of embedded microstrip lines and striplines in an LTCC module with the height of 400 μm.

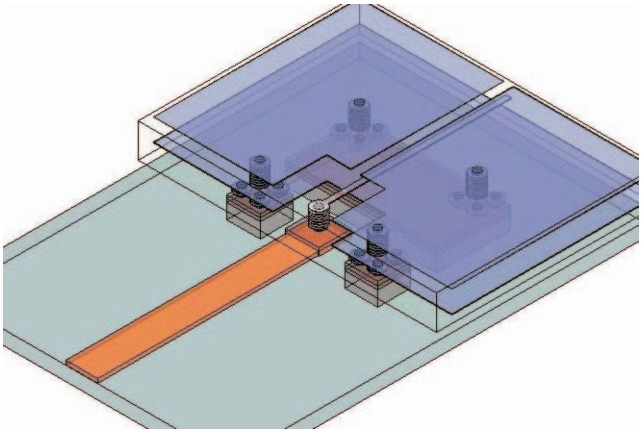


Fig. 5. Model of a single PCB-module transition for the advance of less reflection. Varying the geometry of the cut made in the ground plane affects the matching.

shown in Fig. 3c. Varying the slot width s offers a continuous tuning of the line impedance. In comparison to a classical stripline the isolation level is only slightly reduced, which was investigated by electromagnetic simulations. Fig. 5 shows the electromagnetic model of a single PCB-module transition, which was used for the minimization of the reflections. The reflection at the PCB-module transition is affected by the geometry of the cut made in the bottom and top ground planes. Choosing the right geometry minimizes the reflections.

In order to prove our concept, we have designed an additional test module to determine the neutrality of the connections. It comprises electrically neutral connections and a mirrored version adhered creating symmetric through connections, see Fig. 1c.

III. Neutral Test-PCBs

The design of the test PCB can influence the filter characteristic [4], thus the test PCB has to be designed carefully. In respect to the proposal for the design of neutral test PCBs [5], we have designed two test PCBs for the characterization of duplexer inserts and electrically neutral connections, see Fig. 6.

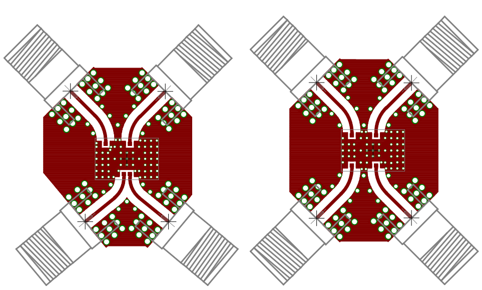


Fig. 6. Test-PCBs for the measurement of test module comprising the duplexer insert (left) and the symmetrical through connections (right).

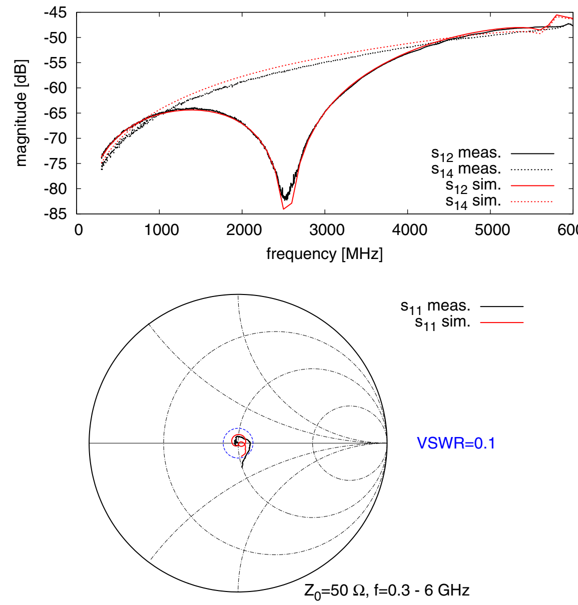


Fig. 7. Measured (black) and simulated (red) scattering parameters of the symmetrical through connections to prove their neutrality. Top graph: s-parameters s_{12} and s_{23} of the backward and forward crosstalk paths respectively; bottom graph: s-parameter s_{11} of the return loss.

IV. Simulated and Experimental Results

In the following sections we will present simulated and experimental results of our W-CDMA1900 duplexer insert in a LTCC test module. For the filtering function a SAW die with an HTCC housing in EPCOS' flip-chip package technology was used. The SAW die contains the single-ended Tx-filter and the balanced Rx-filter being self-matched to 50 Ω and 100 Ω, respectively. The balanced Rx-port of the duplexer insert has a direct connection to the footprint. Tx and Ant are connected via stripline with slotted ground to the Tx-port and antenna-port of the module, respectively, as shown Fig. 1b. The notation of the scattering parameters introduced in Fig. 2 will be used in the following. The electromagnetic characterization of the test modules were done with commercial MoM and FEM simulators.

A. Neutrality of Electrical Connections

In order to prove the neutrality of the connections the test module with the symmetrical through connections has been measured on the test PCB, see Fig. 6b. The backward and forward coupling paths s_{12} and s_{23} respectively, are shown in Fig. 7. The isolation level of around 60 dB between the signal paths are sufficient for the precise characterization of the duplexer inserts. The agreement of simulation and measurement is nearly perfect. Keeping in mind that we have measured the doubled neutral connection, the isolation level of neutral connections used in the test module can be assumed to be 6 dB lower.

Fig. 7b show the measured and simulated reflection coefficients s_{11} of the test module. The good overall matching is evident. The VSWR is less or equal than 0.1 which corresponds to a return loss less or equal than -20 dB over almost the whole frequency range of 0.3 – 6 GHz. Only for high frequencies, far away from the passband of the W-CDMA1900 duplexer, the return loss is slightly higher than -20 dB. These results prove the neutrality of the designed connections which enables the characterization of the duplexer insert in the module environment.

B. Duplexer Insert in Test Module Environment

To get an impression of the influence of the neutral connection on an isolated duplexer insert, the simulated scattering parameters of two different electromagnetic models of the W-CDMA1900 duplexer are compared, see Fig. 8. The first model comprises only the duplexer insert, which allows smart and fast optimization. Referring to the notation of Fig. 2, s_{65}, s_{57}, and s_{67} are representing the scattering parameter of the Tx-antenna path, Rx-antenna path, and the Tx-Rx isolation of the duplexer insert, respectively. The second model comprises the duplexer insert and the stripline with slotted ground. The connections should have as little influence as possible on the performance of the duplexer insert. Regarding Fig. 8, some influence of the connections on the duplexer insert can be noticed, especially isolation and attenuation in the Rx-band, but no critical degrading or improving of the performance occurs.

Moving to Fig. 9, we present a comparison of measured and simulated scattering parameters of a W-CDMA1900 duplexer insert in a test module soldered on a neutral test PCB. The agreement of measurement and simulation is good.

V. Conclusion

We have presented, to the best of our knowledge, the first approach to measure duplexer insert without the influence of other subsystems. We have explained the basic principles of the design of neutral connections and their possible influence on the characterization of duplexer inserts. We have used a stripline with slotted ground, which offers high isolation and the usual impedance of 50 Ω in low profile modules. The experimental result of a W-CDMA1900 duplexer insert shows that we have successfully tested the performance of the duplexer insert in module environment by means of using neutral connections. These have only slight influence on the electrical behavior of the duplexer insert at the reference interface.

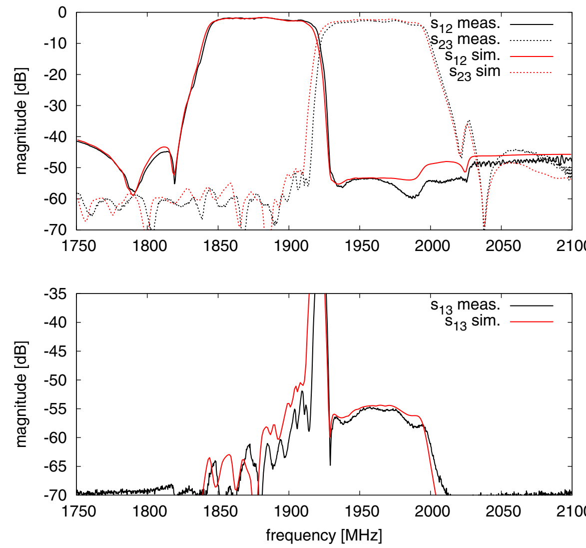


Fig. 9. Comparison of measured (black) and simulated (red) scattering parameters of a test module comprising the W-CDMA1900 duplexer insert. Top graph: s-parameters s_{12} and s_{23} (mixed mode representation) of the Tx-antenna path and Rx-antenna path, respectively; bottom graph: s-parameter s_{13} of the Tx-Rx isolation.

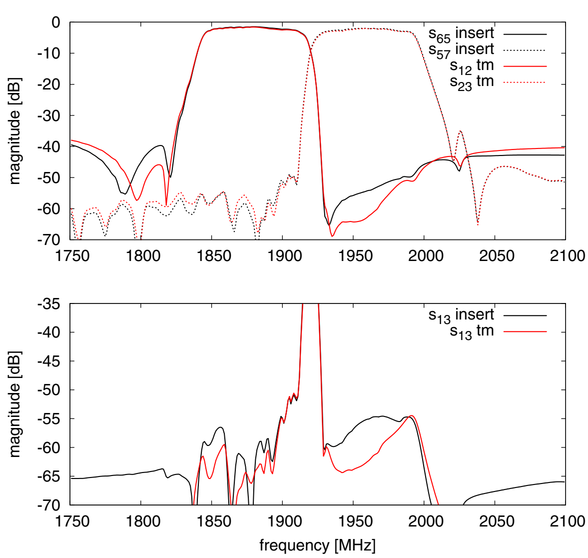


Fig. 8. Comparison of simulated scattering parameter of the W-CDMA1900 duplexer insert "isolated" (black) and in test module environment (red). Top graph: s-parameters s_{12} and s_{23} (mixed mode representation) of the Tx-antenna path and Rx-antenna path, respectively; bottom graph: s-parameter s_{13} of the Tx-Rx isolation.

VI. Acknowledgment

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