Design and measurement of LTE diplexers for Radio-over-Fiber system

Lajos Budai and János Ladvánszky

***Abstract*—Recently the rapidly growing demand for high capacity radio access networks requires new designing and implementation approaches for deploying small LTE radio cells. The reduction of the cell size brings along new solutions for developing cost-efficient equipment. Such a solution, particularly the Radio-over-Fiber technique, detaches the radio frequency signal processing unit from the outdoor transceiver equipment. The goal of this paper is to present planning and measurement steps of the LTE based diplexers, being part of a RoF system, operating around the {2510 MHz, 2690 MHz} and {1710 MHz, 1890 MHz} frequency bands.**

***Index Terms*—Diplexer, Long Term Evolution, microstrip filters, microwave circuits, microwave design, Radio-over-Fiber networks**

I. Introduction

Nowadays high speed communication solutions are highly required to provide high capacity throughput in modern radio access networks (RAN). The Radio-over-Fiber (RoF) technique offers a low-cost and power-efficient solution by physically separating the radio frequency (RF) signal processing components from the transceiver unit. More industrial and academic research in applying such a solution as above are highly needed to face the challenge of deployment and maintenance of Long Term Evolution (LTE) capable base stations.

In this article the basic concept of the RoF system is presented by a test system. This system is intended to be a demonstration network for test measurements in the LTE frequency bands: {2510 MHz, 2690 MHz} and {1710 MHz, 1880 MHz}.

In section II the motivation of the project is discussed and the setup of the demo link presented. In section III the design requirements are described and the design of the diplexer and bandpass filters (BPF) is introduced in details. In the fourth section the measurement results of the diplexer and filters are presented by comparing them with the simulations. The final section presents the conclusion and future achievements.

II. RoF Demo Project

The principal motivation of the project is to create an LTE capable RoF network and its components for demonstrational measurements and research in academic circumstances.

The RoF demo link consists of two software defined radio (SDR) modules interconnected with optic fiber cable carrying LTE signals. The SDR module, functioning as a transceiver, transmits the signal through the RF module. At the receiver side the RF module contains a Wilkinson hybrid element, at the transmitter end of the link the RF unit is made of band selective diplexer, where the selectivity is provided by bandpass filters. To achieve the optical signal transportation, the electrical-optical conversion is realized by small form pluggable (SFP) modules. The structure of RoF link is shown in Figure 1.

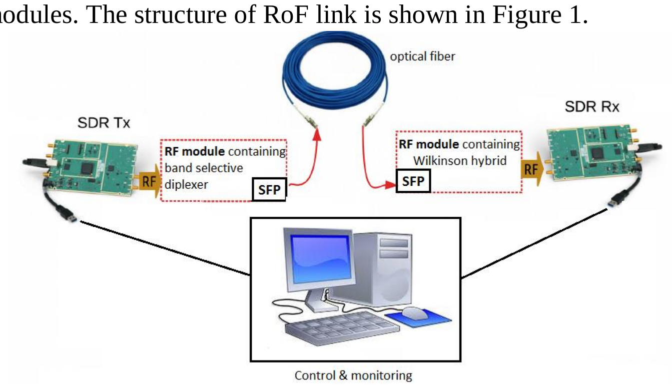

Fig. 1.: RoF demo link

Another objective of the project is to develop and implement circuits which must be compact, easily attachable to transceiver unit and ready for low-cost production in the academic laboratory.

III. Performance Criteria and Design

The operating frequency bands are {2510 MHz, 2690 MHz} and {1710 MHz, 1880 MHz}. The frequency bands have been chosen by virtue of the actual regulations of the Hungarian National Media and Communication Authority (NMHH) [5] and the recommendations based on the LTE standard [6]. The given parametric specifications related to the diplexer are the following (Chart 1.):

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Insertion loss [dB]		Operating frequency range [MHz]
Maximum at bandpass frequencies	Minimum at bandstop frequencies of each output channels	
6	20	{1710 MHz, 1880 MHz}
		{2510 MHz, 2690 MHz}

Chart 1.: Parametric criteria for the diplexer

In this section we introduce the design procedure of RF module. Regarding to high operating frequencies, microwave design techniques were considered and for circuit design the *AWR Design Environment 2010* software was chosen. Due to the physical properties and operating attributes, we decided that the circuit's structure has to be implemented by microstrip transmission lines.

In an overall overview in the transmitter unit the diplexer consists of Wilkinson power divider and bandpass filters providing the selection of the bands for the outputs [2]. The receiver unit is only made of Wilkinson hybrid. Considering our previous experiences and the available resources we have chosen the Rogers RO4003C substrate for microwave circuits. The Rogers substrate's material has optimal properties for high frequency applications: the *dissipation factor (tanδ)* and the *dielectric constant* (ε_r) are **0.003** and **3.6**, respectively. These values are different from manufacturer's specifications and were corrected due to the precise measurement considering their frequency dependence. The measurement is described in [7].

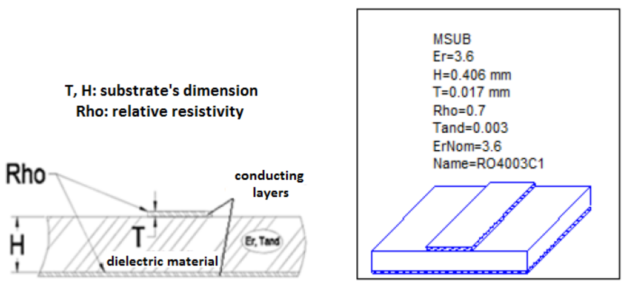

Fig. 2.: Parameters of RO4003C substrate

In the start the characteristic impedance (Z_0) is chosen to be 50Ω. The microstrip transmission line width is calculated based on [1]:

$$\frac{W}{h} = \frac{2}{\pi}\left((B-1) - ln(2B-1) + \frac{\varepsilon_{er}-1}{2\varepsilon_{er}}\left[ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_{er}}\right]\right),$$

$$where\ B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_{er}}}\ and\ \varepsilon_{er}\ relative\ dielectric\ constant \qquad (1.)$$

The line width is **W=0.88mm** at 2.2GHz center frequency (f_c).

The Wilkinson hybrid is a 3-port power divider consisting of two lamdba/4 transformer lines having a bridging resistor near the input. The value of resistor is $2xZ_0$=100Ω. In the knowledge of the center frequency, the length and the width of the transformer line is calibrated to **20.35mm** and **0.47mm**, respectively.

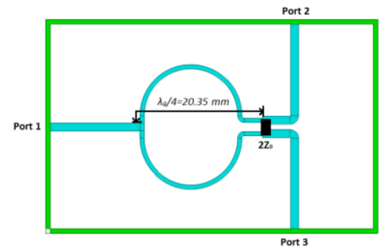

Fig. 3.: Layout view of the Wilkinson hybrid.

The simulation results of the scattering parameters (Fig. 4.) shows that the return loss is greater than 19dB around examined frequencies. The transfer function predicts the insertion loss is less than 3.2dB.

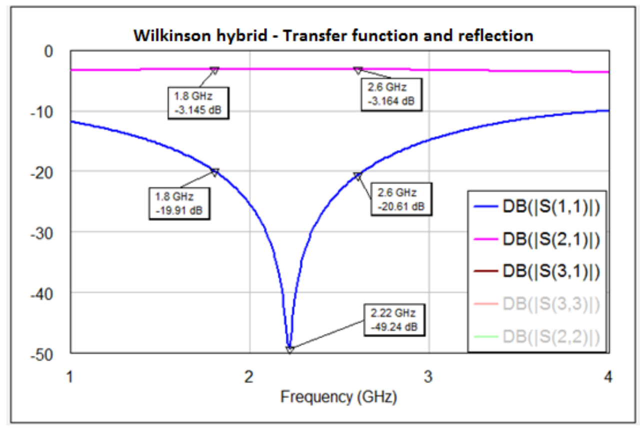

Fig. 4.: Simulation results – transfer function (S12 & S13), reflection (S11, insertion loss)

At the transmitter end, in the band selective diplexer the frequency separation of each channel is provided by microstrip bandpass filters. We have decided to design two variants of filters. The first BPF variant is a *three-pole pseudocombline* filter (Fig. 5./a) having made of three λ/4 long transmission lines each grounded on one end with a via. The other variant is a *two-pole coupled-resonator* filter consisting of two λ/2 long quadratic resonator line (Fig 5./b) [3]. After calculating the lengths of the lines, the optimization - at 1.8GHz and 2.6GHz - of each filter's transfer function has resulted their final dimensions presented in the chart below (Figure 6.).

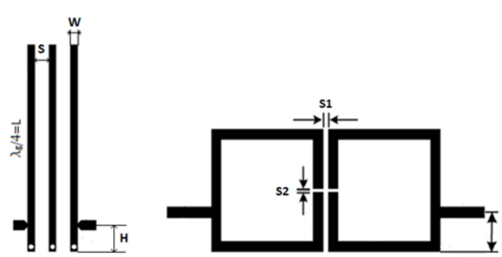

Fig. 5./a and 5./b: Structure and dimensions of the pseudocombline filter and of the coupled-resonator filter

fo [GHz]	W [mm]	H [mm]	L [mm]	S [mm]
1.8	0.80	3.93	24.87	0.50
2.6	2.71	2.70	17.21	0.10

fo [GHz]	S1 [mm]	S2 [mm]	L [mm]	L1=λg/2 [mm]
1.8	0.15	0.1	1.75	49.74
2.6	0.1	0.4	0.50	34.43

Fig. 6.: Dimensions of the filters after optimization

Before finalizing the diplexers' layout, further length optimization of interconnecting transmission lines were needed to achieve better performance. The adjusted optimization goals in AWR were the following: *S12,S13>6dB and S11<-12dB*. The simulation results of the proposed diplexer are shown in Figure 7. and 8. The diplexers have each type of the bandpass filters.

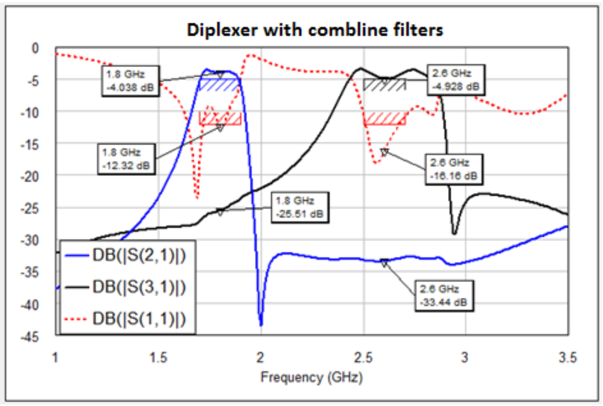

Fig. 7.: Simulation results of the diplexer with combline filter (return loss – dashed line, insertion loss – continuous line)

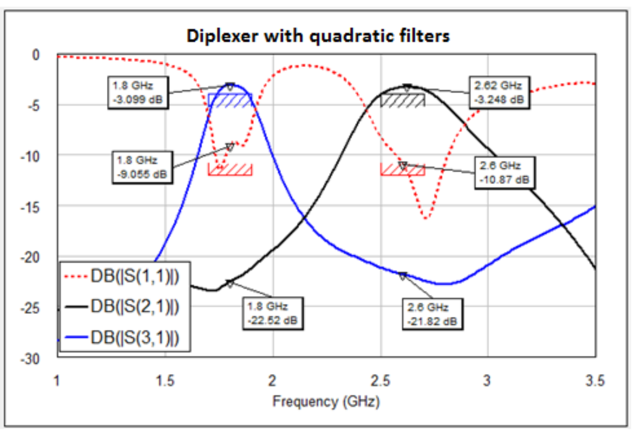

Fig. 8.: Simulation results of the diplexer with quadratic resonator filters

Each circuit realization has advantages over the other: the quadratic filter variant has better performance in insertion loss and the combline variant has minor return loss compared to the other. Taking everything into account the simulation results satisfy the performance requirements described above in this section.

IV. Implementation and Measurement

The circuits were fabricated in one of the academic laboratory. During the manufacture process on one side the metallic layer was scoured based on the previously sent gerber files of layout schematics. After the dipping the circuit layouts were formed. The final phase was the implantation of the surface mounted connectors (SMA) and resistors.

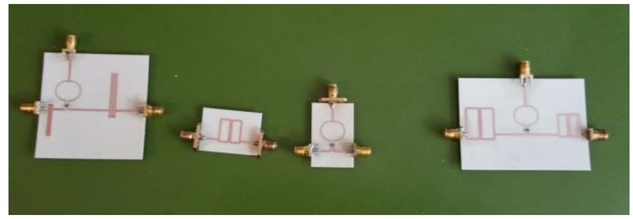

Fig. 9.: Completed circuits

The measurements were performed in laboratory environments having an average 25°C ambient temperature.

For measuring each circuit's transfer function and reflection the *HP 8722D* network analyzer was used. Figure 10 – 13 represents the measurements of filter circuits.

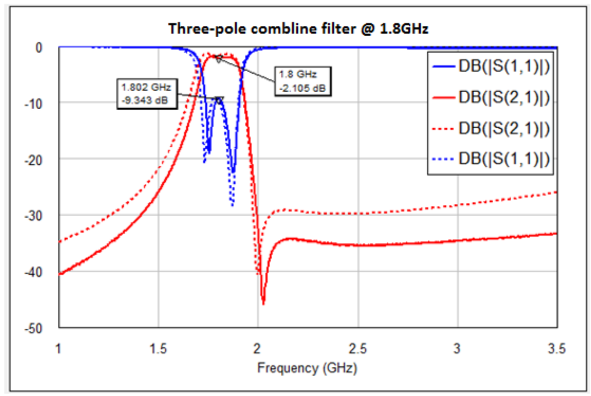

Fig. 10.: **Reflection** and **transfer function** (dashed line – simulation, continuous line – measurement)

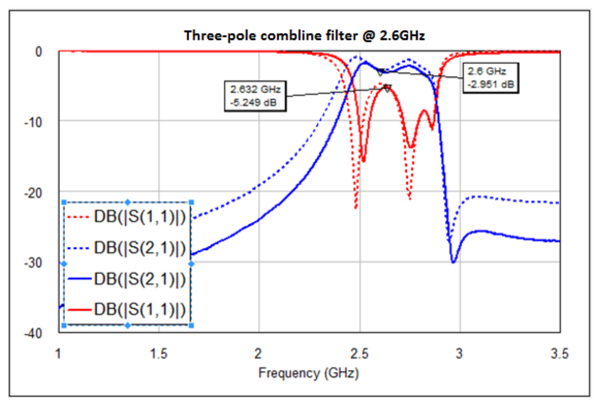

Fig. 11.: **Reflection** and **transfer function** (dashed line – simulation, continuous line – measurement)

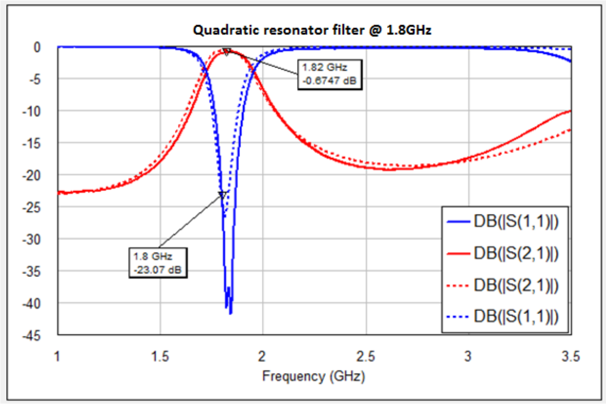

Fig. 12.: **Reflection** and **transfer function** (dashed line – simulation, continuous line – measurement)

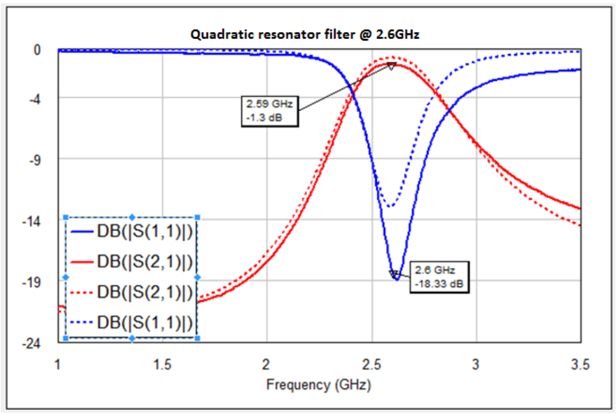

Fig. 13.: **Reflection** and **transfer function** (dashed line – simulation, continuous line – measurement)

Considering the results on the graphs above the minor differences may originate from manufacturing inaccuracy and soldering defects. Figure 14-17 represent the measurement results of the diplexers.

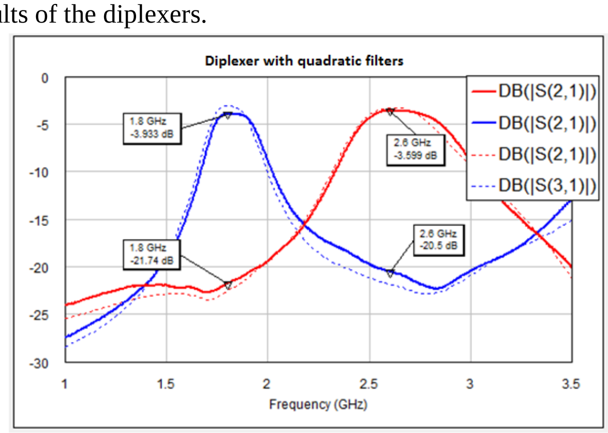

Fig. 14.: Transfer functions of each channels (dashed line – simulation, continuous line – measurement)

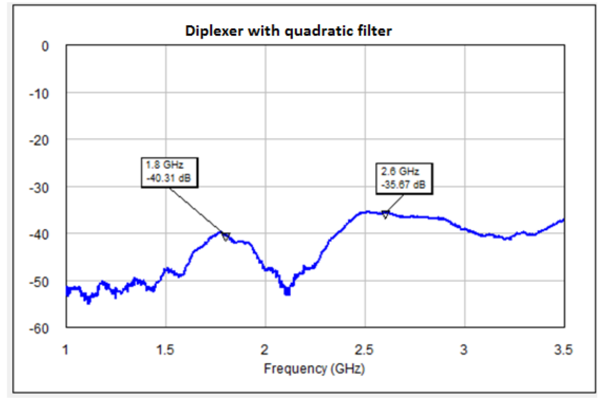

Fig. 15.: Channel isolation (measured between the outputs)

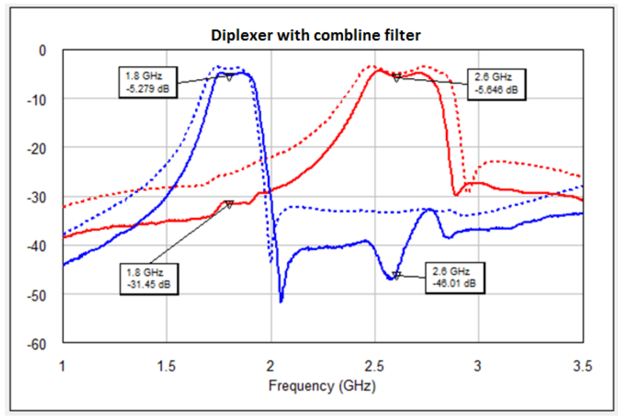

Fig. 16.: Transfer functions of each channels (dashed line – simulation, continuous line – measurement)

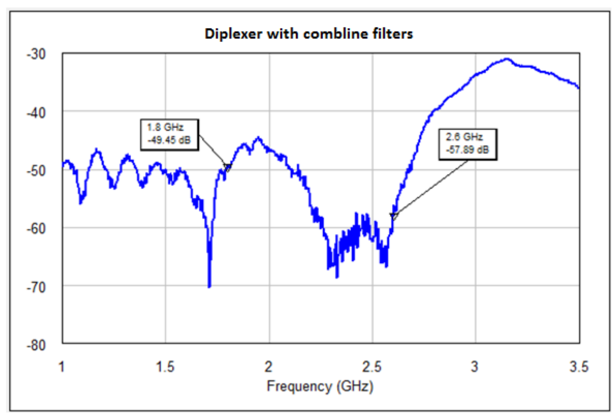

Fig. 17.: Channel isolation (measured between the outputs)

From the graphs above we can verify good correspondence between the measured and simulated transfer functions. The channel isolation of each type of diplexers is greater than 30dB.

V. Conclusion and Future

Comparing the results, the circuits satisfy the requirements described in section III, and will be utilized in one variant of the RF module.

The next step of the project will be the design and implementation of another version of this diplexer which mixes down the signal to baseband frequencies in MHz range.

VI. Acknowledgement

This work is intended as our modest commemoration of the 100th anniversary of Prof. K. Simonyi's birth.

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János Ladvánszky (MSc in electrical engineering, Candidate of technical science (equivalent of PhD)) graduated from secondary school in Törökszentmiklós in 1973, with highest distinction. Then he completed a year of military service in Debrecen. During that time he taught his mates for radar techniques, at the age of 18. He was a student at the branch of Technical Physics B, Faculty of Electrical Engineering, Budapest University of Technology. He defended his thesis „Modelling of a microwave transistor" with distinction. During university years he took part in competitions in mathematics, circuit theory and foreign languages, with several awards. He worked out his scientific student works in 1977, entitled as „Plotting of two-dimensional potential fields" (faculty first prize, national second prize, participation at international student's scientific conference), and „Analysis of a diode phase detector" (faculty first prize, university first prize, rector's prize, national first prize, participation at international student's scientific conference). His average mark was always above 4.5, once 5.0. He won the Stipend of the People's Republic 6 times. He started working in 1978 at the Research Institute for Telecommunications, at the Microwave department, resulting in a dissertation „Problems of nonlinear, microwave circuit design" that was defended in 1988 with maximum scores. In 2000 he was invited at the Budapest office of the Austria Mikro Systeme AG, then to the headquarter of the firm at Graz, Austria, to the department of vehicle electronics. There he learnt system level thinking. Since 2010 he has been with Ericsson Telecom Hungary Ltd., in several topics: noise reduction, MIMO, signal integrity, Radio over Fiber. He got several patents. Total number of publication is 159, from which the number of accepted papers, lectures and patents is 55 since the PhD degree. He likes consulting students, with outstanding results: 1st prize at the Student's Scientific Conference, 1st prize at the Ericsson Student's Conference several times, 1st prize of the Scientific Association for Telecommunications and many other prizes. He participated at several international conferences, he presented several invited talks and he was Session Chairman several times, in Europe, North and South America, and in the Far East. Number of his ResearchGate downloads exceeds 800 since February 2016. From 1985 to 1997 he was a member of the Telecommunication System's Committee of the Hungarian Academy of Sciences. His most important result in connection with his committee membership is the study entitled as „Scientific overview of communications technique 1988" that was prepared for the Hungarian government. As a guest researcher he was in Helsinki, Bologna, Gothenburg and Stockholm (several times). His DSc dissertation „Circuit and system design for optical communications" is the result of a 30-year research work.