A 900 MHZ LADDER-TYPE SAW FILTER DUPLEXER

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ABSTRACT

A low-cost hybrid-integrated SAW filter duplexer consisting of receiver top filter, transmitter final-stage filter and antenna terminal has been developed. The prototype design was oriented at the GSM system specifications in the 900 MHz-band. Three-stage ladder-type SAW filters have been designed to perform the duplexing function by the use of only one transmission line. The complete duplexer has an insertion loss of 1.2 dB in the Tx path (Tx) and 2.1 dB in the Rx path (Rx). The 3 dB-bandwidth is 40.1 MHz (Tx) and 47.4 MHz (Rx), respectively.

INTRODUCTION

The *Global System for Mobile Communication* (GSM), which has started operation in Europe, employs frequency division duplexing (FDD) and FDMA/TDMA subscriber access in the 900 MHz band. Transmitter (Tx) band, receiver (Rx) band and bandwidth are respectively 890-915 MHz, 935-960 MHz and 25 MHz. As is the case with many digital cellular phone systems like PCS in the United States, PCN/DCS1800 in Europe, and JDC in Japan, in GSM transceivers as front-end filters both in the Tx- and the Rx-path surface acoustic wave (SAW) filters are going to replace competing filter technologies due to their low insertion loss, small size and high reproducibility at a low price [1]. Among the various SAW filter low-loss techniques is the ladder-type technique which has recently been established for the use in advanced mobile devices. In what follows, we report on the design and performance of a SAW duplexer prototype for the GSM system. As SAW low-loss RF filters, ladder-type filters fabricated on $LiTaO_3$ have been used.

PRINCIPLE OF OPERATION

The antenna duplexer consists of a two-way antenna terminal, a transmitter final-stage filter T1, and a receiver top filter R1. It provides simultaneously both filtering and diverging. The duplexer ensures that transmitter power, which is typically in the order of 30 dBm, does not flow into the receiver and receiver signals, which are typically in the order of -120 dBm, do not suffer attenuation by flowing into the transmitter. In [6], the microstrip antenna terminal incorporated two quarter wavelength transmission lines as well as two printed inductances and two lumped capacitances covering an epoxy substrate which was 1x1 inch^2 in dimension. Our present design aimed at avoiding these many elements - in particular the lumped elements - by properly designing the SAW filters T1 and R1.

LOW-LOSS SAW FILTERS

A ladder-type filter consists of a number of SAW resonators integrated on a single chip [2],[3]. We use a three-stage ladder-ty-

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pe structure incorporating five one-port resonators as is shown in Fig. 1.

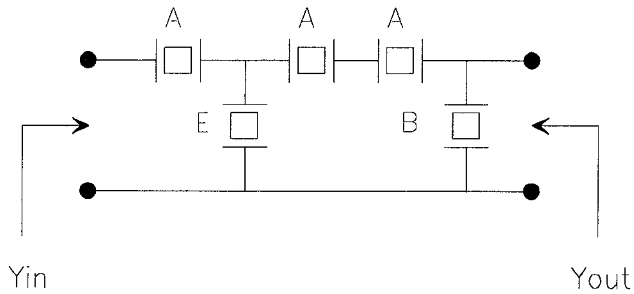

Fig. 1: Structure of three-stage ladder-type filter consisting of five one-port resonators A,B, and E.

In order to achieve wideband operation in a 50 Ω environment, 36°rotYX $LiTaO_3$ has been used as a substrate material due to its high electromechanical coupling factor of 6 to 7 per cent and its rather low temperature dependency of frequency of -30 ppm/K. Traditional LC filter design rules are applied as a first approximation to define the stopband rejection level, the roll-off factor and the passband ripple. The next design step is based on P-matrix simulations which account very accurately for the pertinent characteristics of leaky SAW (LSAW) propagation such as dispersion, attenuation, reflection, coupling, and others [4]. A final microwave design is then carried out which includes also parasitics due to package effects and chip layout effects (such as stray capacitances and inductances, electromagnetic feedthrough, Ohmic losses, coupling inductances, and others) [5].

The filters T1 and R1 require not only the frequency characterisitcs but also fixed input and output impedances due to their parallel connection at the antenna terminal. Let Z_T and Z_R be respectively the impedance of T1 and R1 looking from the antenna side. At the passbands of the filters, Z_T and Z_R must be near 50 Ω, and at the mutual frequency bands f_T (Tx path) and f_R (Rx path) they must have very high values since, when T1 and R1 are connected in parallel, the insertion loss of each filter increases due to the mutual interactions of Z_T and Z_R. Thus, the impedances Z_T and Z_R must be properly designed employing appropriate SAW filter types, structures and parameters.

For both T1 and R1 we use the same three-stage ladder-type structure given in Fig.1. The resonator E originates from connecting two resonators of type B in parallel for space saving's sake. It is derived from resonator B mainly by doubling the aperture and adjusting the pad distances. The design parameters such as pitches, number of transducer fingers, number of reflector strips, apertures, distances between transducers and reflectors, pad widths and so on were chosen to meet best the design specifications. Layout and package parasitics were fully taken into account. The SAW filters were mounted into standard 5x5 mm^2 SMD QCC-8 packages. Figs.2, 3 and 4 show as an example the experimental frequency response and the reflection factors S_{11} and S_{22} of the receiver top filter R1 in comparison with the simulated behavior.

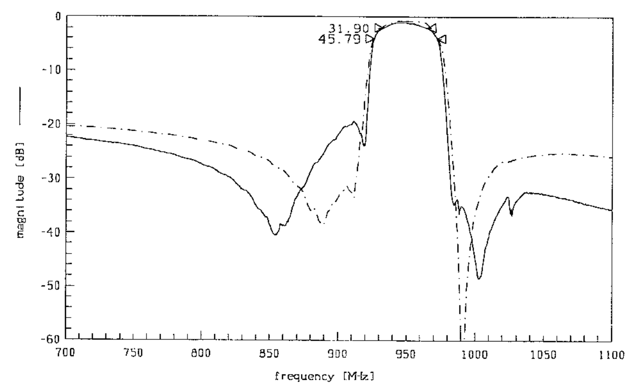

Fig. 2: Experimental (——) and simulated (- - -) frequency response of receiver top filter R1.

As is seen, the agreement between theory and measurement is very good. Insertion loss at center frequency and 3 dB-bandwidth are 1 dB and 44 MHz, respectively. The required matching and mismatching characteristic is achieved quite properly in the respective frequency bands. The experimental results of

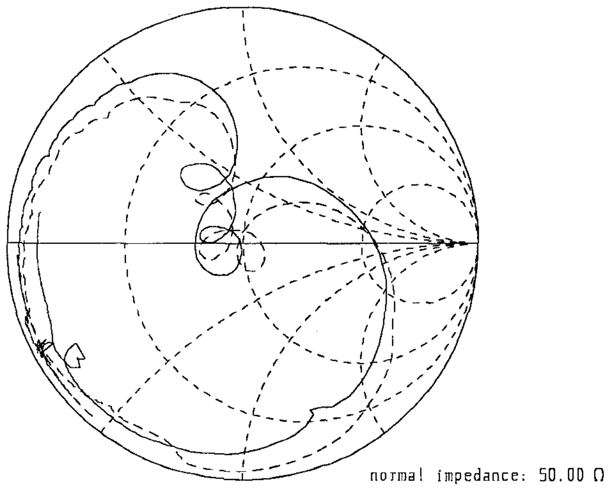

Fig. 3: Experimental (——) and simulated (- - -) reflection factor S_{11} of receiver top filter R1.

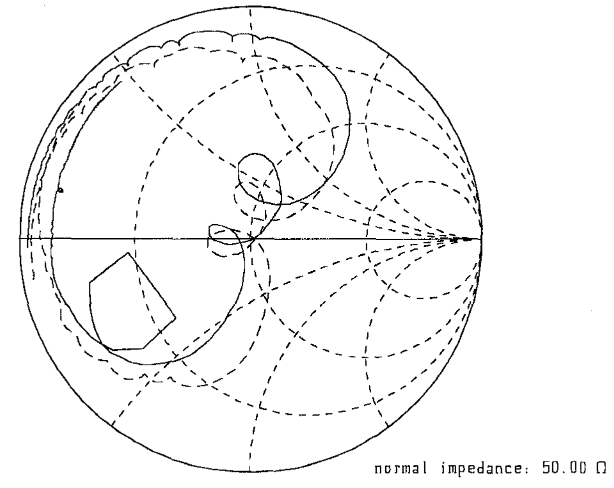

Fig. 4: Experimental (——) and simulated (- - -) reflection factor S_{22} of receiver top filter R1.

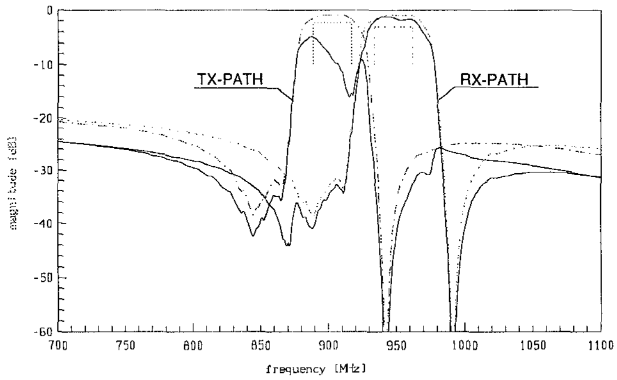

Fig. 5: Simulated frequency response of Tx path and Rx path when simply connecting final-stage filter and receiver top-filter in parallel

the transmitter final stage filter T1 are very similar to those of the receiver top filter R1.

ANTENNA-DUPLEXER

When connecting R1 and T1 directly without any elements for impedance transformation one would obtain the frequency response shown in Fig. 5 which is of course not acceptable.

We found that the distortions can be removed by inserting only a single transmission line TL1 between R1 and the antenna terminal (Ant) as is illustrated in the block diagram of the duplexer given in Fig. 6. The incorporation of a second transmission line between T1 and the antenna terminal is not necessary because of the given impedance characteristics. The layout of the duplexer circuit board is shown in Fig.7.

As a microwave substrate, we use low-cost epoxy ($\epsilon = 5$). The dimensions l_1 to l_4, b and c were designed using standard microwave simulation tools. The length of the transmission line TL1 is approximately 4 cm which is about $\lambda/4$ at center frequency. The experimental results for the duplexer are shown in Fig.8 which gives the frequency response of both the Tx path (Ant-Tx) and the Rx path (Ant-Rx). In the Tx path, insertion loss (at center frequency 902.5 MHz) and 3 dB-bandwidth are respectively 1.2 dB and 40.1 MHz, and in the Rx path, insertion loss (at center frequency 947.5 MHz) and 3 dB-bandwidth are respectively 2.1 dB and 47.4 MHz. A small distortion can be observed at the high frequency end of the Ant-Rx path which can be attributed to the influence of the slight impedance transformation due to the transmission line length l_3 (see Fig.7). The selectivity is very good within the upper rejection band but should be somewhat improved in the lower rejection band.

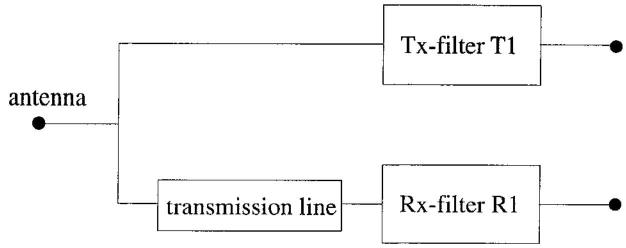

Fig. 6: Block diagram of the duplexer incorporating one transmission line.

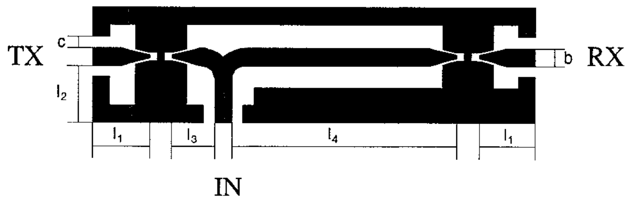

Fig. 7: Layout of duplexer.

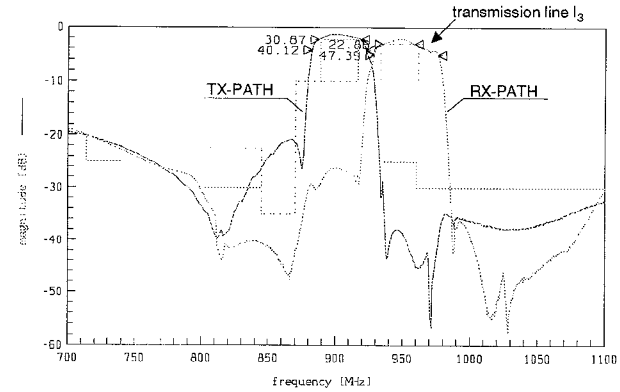

Fig. 8: Duplexer experimental frequency response of Ant-Tx and Ant-Rx path.

CONCLUSION

The present work demonstrates the feasibility of using low-cost hybrid-integrated SAW duplexers at the front-end of FDD mobile radio transceivers. The prototype design was oriented at the GSM system specifications. Wideband ladder-type SAW filters with low insertion loss have been accurately designed in order to perform the duplexing function with the complexity being as small as possible. Only one transmission line with a length of about $\lambda/4$ had to be used. Currently, the integration of the duplexer directly on $LiTaO_3$ is under work - a measure by which the size of the duplexer is furthermore reduced due to the high ϵ of $LiTaO_3$.

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