Balanced Front-End SAW Modules with Improved Selectivity at Low Frequency Offsets for Handheld Transceivers

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***Abstract*—This paper presents the new balanced front-end SAW modules with the improved selectivity at the low frequency offsets and fractional bandwidth of 1.5-4% for the 440-470 MHz handheld transceivers. The modules contain 2 SAW filters connected across a low noise bipolar transistor amplifier. The balanced longitudinally-coupled resonator SAW filters on 42° YX $LiTaO_3$, 64° YX, 41° YX $LiNbO_3$ were used in these modules to suppress the high frequency (HF) shoulder in the frequency response. The first filter is realized in a 4-pole three-transducer scheme. The second filter with a wider fractional bandwidth is realized in the 4-pole two- or three-transducer scheme. A combination of these two types of the filters with the different fractional bandwidths provides an efficient suppression of the HF shoulder in the frequency response of the modules. The optimization of a SAW filter-amplifier-SAW filter system is provided with a computer simulation using an equivalent circuit model. The 440-470 MHz samples of the balanced front-end modules have shown an amplitude ripple of 1 dB within a 3-dB bandwidth of 6.6-20.2 MHz, 10 dB gain, improved suppression up to 60 dB at the low offsets of ±13÷ ±30 MHz from the center frequency. The modules provided a noise factor of 2 dB with a current consumption of 5-7 mA and supply voltage of 3 V in the 13.3x6.5x1.8 mm SMD packages.**

I. Introduction

The balanced low-loss longitudinally-coupled resonator (LCR) SAW filters are successfully employed in the balanced hybrid SAW modules for high frequency handheld transceivers [1]. However these modules have a high frequency (HF) shoulder with a relative level of 30-45 dB at the low frequency offsets from a center frequency. It is relate with a frequency response form of the LCR SAW filters [2]

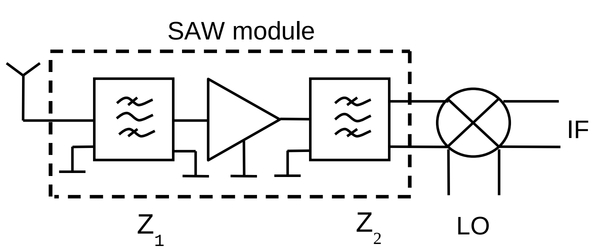

Figure 1. Balanced front-end SAW module

employed in these modules. This paper presents the new balanced front-end SAW modules with the improved selectivity at the low frequency offsets and fractional bandwidth of 1.5-4% for the 440-470 MHz handheld transceivers. The modules contain 2 SAW filters connected across a low noise bipolar transistor amplifier. The balanced LCR SAW filters on 42° YX $LiTaO_3$, 64° YX, 41° YX $LiNbO_3$ [3] with the different fractional bandwidths were used in these modules to suppress the HF shoulder in the frequency response. The first filter has the unbalanced/balanced input and unbalanced output. The second filter has the unbalanced input and balanced output. The modules are connected between an antenna and double balanced mixer in the front-end of the handheld transceivers and provide the local oscillator and image frequencies suppression (Fig. 1).

II. Balanced LCR SAW Filters for Module

For a 1.5% fractional bandwidth module the first balanced filter Z_1 is realized in a 4-pole three-transducer (3t) scheme on 42° YX $LiTaO_3$ on the longitudinal first and third resonant modes (Fig. 2) [2]. The second balanced filter Z_2 with a wider fractional bandwidth is realized in the 4-pole 3t scheme or two-transducer (2t) scheme on the longitudinal first and second resonant modes (Fig. 3) [2]. These two types of the filters have a different distribution of the HF shoulders in the frequency responses. A combination of these two types of the filters with the different fractional bandwidths and slight frequency shift between them provides an efficient suppression of the HF shoulder in the frequency response of the modules. As an example we can demonstrate this for the combination of the filter with a fractional bandwidth of 2% on 42° YX $LiTaO_3$ and the filter with a fractional bandwidth of 4% on 64° YX $LiNbO_3$. Fig. 4 shows a frequency response of the first 443 MHz 3t LCR SAW filter Z_1 on 42° YX $LiTaO_3$. In a symmetrical 50-Ω system the filter had an insertion loss of 2.5 dB, 3-dB bandwidth of about 10 MHz, stopband attenuation (HF shoulder) of about 25 dB at 12.6 MHz offset from the center frequency. The frequency response of the second 443 MHz 3t LCR SAW filter Z_2 on 64° YX $LiNbO_3$ is shown in Fig. 5. In a symmetrical 50-Ω system the filter had an insertion loss of 2.7 dB, 3-dB bandwidth of 19.1 MHz,

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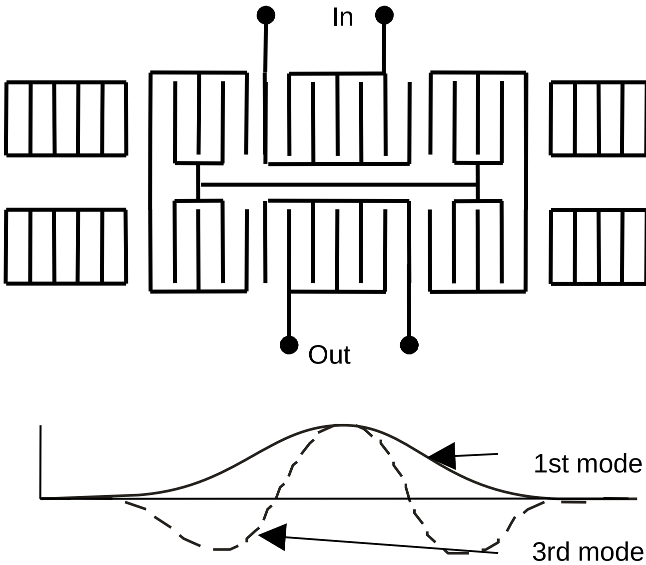

Figure 2. Balanced 4-pole three-transducer resonator SAW filter on the longitudinal 1st and 3rd modes

HF shoulder of about 30 dB at 25.8 MHz offset from the center frequency. Fig. 6 shows a frequency response of the 443 MHz 2t LCR SAW filter Z_2 on 64° YX $LiNbO_3$. In a symmetrical 150-Ω system the filter had an insertion loss of 3 dB, 3-dB bandwidth of about 14.9 MHz, HF shoulder of about 25 dB at 22 MHz offset from the center frequency. An analysis of these frequency responses shows that the filters Z_1 and Z_2 differ greatly in the stopband to the right of the center

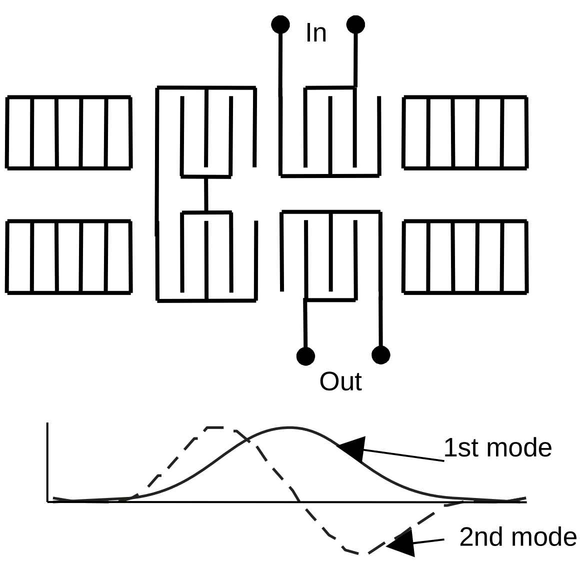

Figure 3. Balanced 4-pole two-transducer resonator SAW filter on the longitudinal 1st and 2nd modes

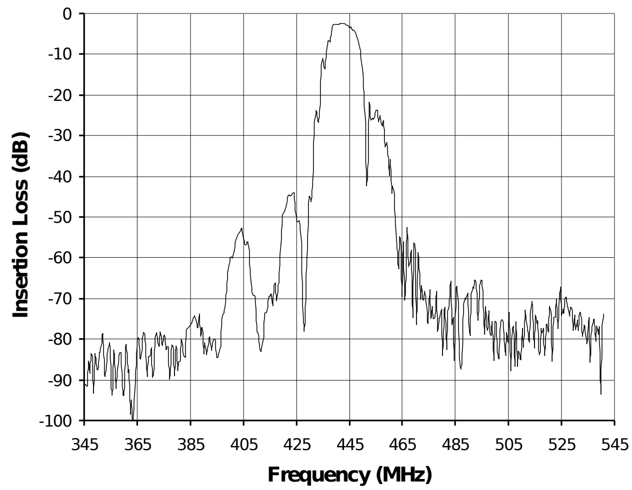

Fig. 4. Frequency response of the 443 MHz balanced 3t LCR SAW filter on 42 – YX $LiTaO_3$

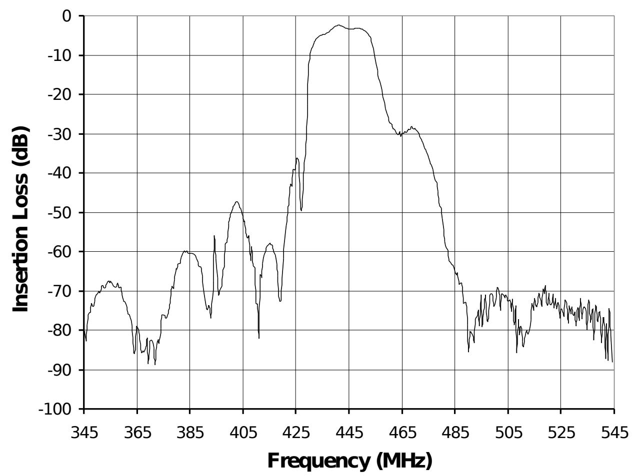

Fig. 5. Frequency response of the 443 MHz balanced 3t LCR SAW filter on 64 – YX $LiNbO_3$

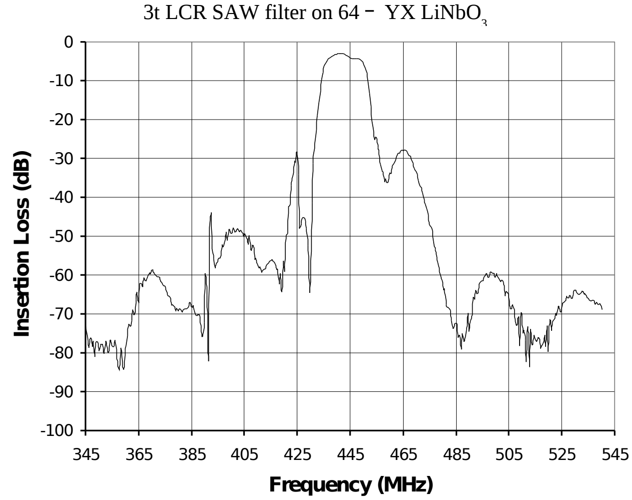

Fig. 6. Frequency response of the 443 MHz balanced 2t LCR SAW filter on 64 – YX $LiNbO_3$

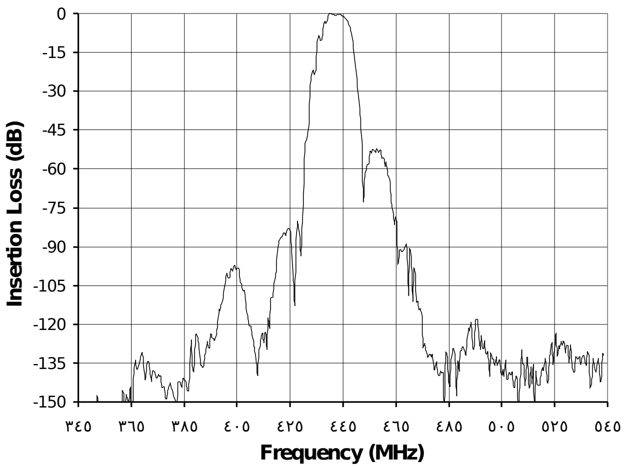

Fig. 7. Simulated normalized frequency response of the SAW module

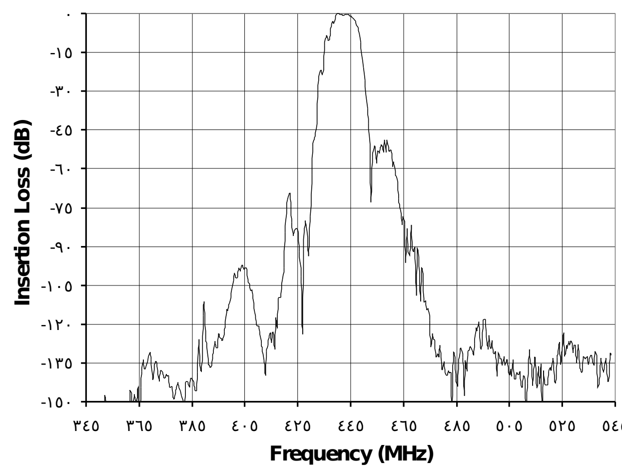

Fig. 8. Normalized frequency response of the 443 MHz SAW module with 1.7% fractional bandwidth with LCR filters on 42 − YX $LiTaO_3$ (3t) and 64 − YX $LiNbO_3$ (2t)

frequency. If the filters Z_2 are slightly shifted down in frequency with reference to filter Z_1 the total frequency response of the filters Z_1xZ_2 have low HF shoulder. This fact can be used to increase the selectivity of the combination from the two filter types (for example in the SAW module) at low offsets from the center frequency. A similar method can be shown for realization of the filters for the module with a fractional bandwidth of 4%. For this purpose the balanced 3t LCR SAW filters on 64° YX $LiNbO_3$ and 2t or 3t LCR SAW filters on 41° YX $LiNbO_3$ can be used [2, 3].

III. Development of the Balanced SAW Modules

The development of the balanced SAW modules was provided by means of an optimization of a SAW filter-amplifier-SAW filter system using a computer simulation according to an equivalent circuit model [1]. The minimization of SAW filters and amplifier mismatch was carried out to achieve low amplitude ripple in the passband of the module. The optimization of the single stage amplifier with common-emitter bipolar transistor was provided with software MicroCAP. It was necessary for obtaining a low current consumption of 5-7 mA with a supply voltage of 3 V, 10-12 dB gain and the specified input/output impedances close to the input/output SAW filter impedances. Fig. 7 shows the simulated normalized frequency response of 443 MHz filter- amplifier-filter system (prototype module) with the 3t LCR SAW filter on 42° YX $LiTaO_3$ and 2t LCR SAW filter on 64° YX $LiNbO_3$. As will be seen from Fig. 7, the amplitude passband ripple of the prototype module is very low and HF shoulder is low (about 50 dB at 13 MHz offset from the central frequency). The modules were mounted in the 13.3×6.5×1.8 mm SMD packages. The optimization of a module topology was provided to decrease EM feedthrough and achieve high stopband attenuation by selection of the mutual arrangement of the SAW filters, amplifiers and ground bond wires in the SMD package. The measurements were carried out in a measurement system with an input unbalanced load and output balanced load by the network analyzer and balanced transformer. The losses of the balanced transformer were eliminated from the measured insertion losses of the modules. The measured normalized frequency response of 443 MHz balanced module with the 3t LCR SAW filter on 42° YX $LiTaO_3$ and 2t LCR SAW filter on 64° YX $LiNbO_3$ is presented in Fig. 8. The module has shown an amplitude ripple of 0.5 dB within a 3-dB bandwidth of 7.5 MHz (fractional bandwidth of 1.7%), 10 dB gain, HF shoulder of 50 dB at 14 MHz offset. Fig. 7 and Fig. 8 show good agreement between the simulated and measured responses. The measured normalized frequency response of 443 MHz balanced module with the 3t LCR SAW filter on 42°YX $LiTaO_3$ and 3t LCR SAW filter on 64° YX $LiNbO_3$ is presented in Fig. 9.

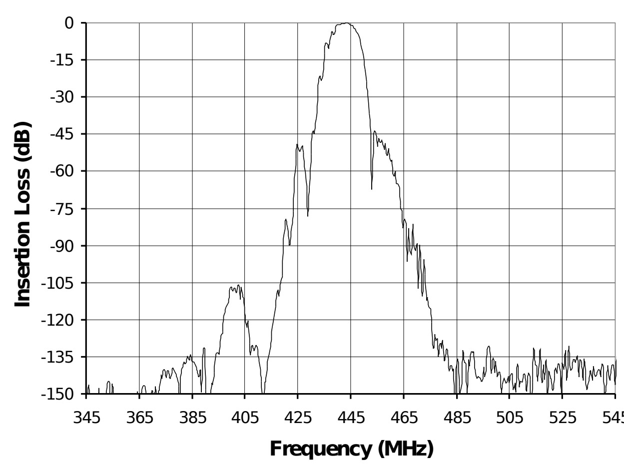

Fig. 9. Normalized frequency response of the 443 MHz SAW module with 1.5% fractional bandwidth with LCR filters on 42 − YX $LiTaO_3$ (3t) and 64 − YX $LiNbO_3$ (3t)

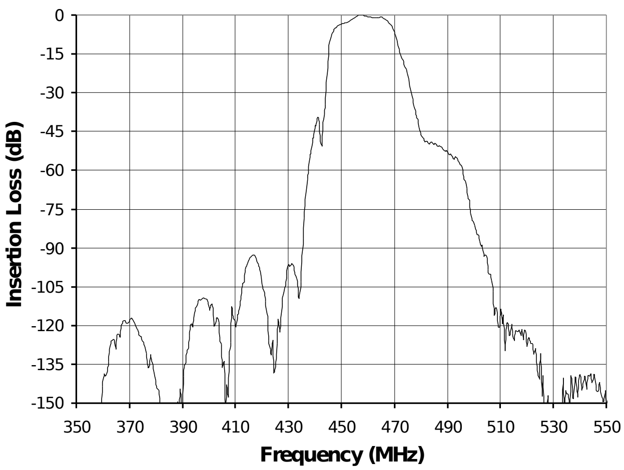

Fig. 10. Normalized frequency response of the 460 MHz SAW module with 4% fractional bandwidth with LCR filters on 64 – YX $LiNbO_3$ (3t) and 41 – YX $LiTaO_3$ (3t)

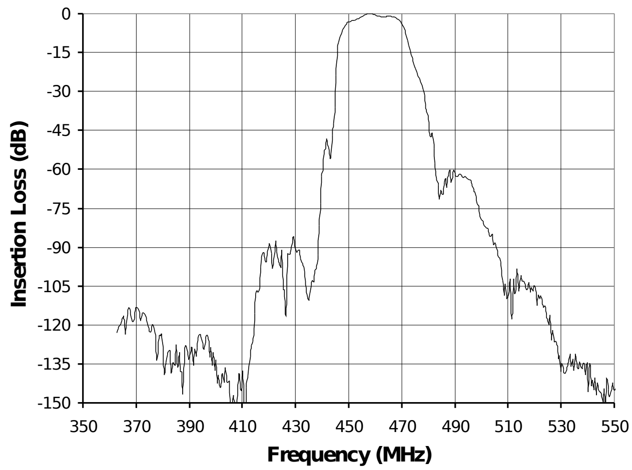

Fig. 11. Normalized frequency response of the 460 MHz SAW module with 4.4% fractional bandwidth with LCR filters on 64 – YX $LiNbO_3$ (3t) and 41 – YX $LiTaO_3$ (2t)

The module has shown an amplitude ripple of 0.5 dB within a 3-dB bandwidth of 6.6 MHz (fractional bandwidth of 1.5%), 10 dB gain, HF shoulder of 45 dB at 14 MHz offset. To extend the bandwidth of the modules the piezoelectrics with a large electromechanical coupling coefficient 64° YX and 41° YX $LiNbO_3$ must be used. Fig. 10 shows a normalized frequency response of 460 MHz balanced module with the 3t LCR SAW filter on 64° YX $LiNbO_3$ and 3t LCR SAW filter on 41° YX $LiNbO_3$. The module has shown an amplitude ripple of 1 dB within a 3-dB bandwidth of 18.4 MHz (fractional bandwidth of 4%), 10 dB gain, HF shoulder of 50 dB at 30 MHz offset from the center frequency. The normalized frequency response of 460 MHz balanced module with the 3t LCR SAW filter on 64° YX $LiNbO_3$ and 2t LCR SAW filter on 41° YX $LiNbO_3$ is presented in Fig. 11. The amplitude ripple of 1 dB within a 3-dB bandwidth of 20.24 MHz (fractional bandwidth of 4.4%), 10 dB gain, HF shoulder of 60 dB at 30 MHz from the center frequency were obtained in this module.

IV. Conclusion

We have developed the new balanced hybrid SAW modules with improved selectivity at the low frequency offsets from a center frequency then the previous ones [1]. A combination of two types of the LCR filters with the different fractional bandwidths on 42° YX $LiTaO_3$ and 64° YX $LiNbO_3$, 41° YX and 64° YX $LiNbO_3$ provides an efficient suppression of the HF shoulder up to 60 dB in the frequency response of the modules. We shall use them in the front-end of 440-470 MHz handheld transceivers for the better suppression of the local oscillator and image frequencies.

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