SAW MICROSTRIP FRONT–END FOR MOBILE COMMUNICATION SYSTEMS IN THE GHZ RANGE

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ABSTRACT

Design, fabrication and performance of a SAW microstrip front–end circuit in the low GHz range for applications in time division multiple access (TDMA) systems are reported. The front–end consists of a transmitter part (containing a SAW filter for noise suppression, and amplifiers), a receiver part (containing a stripline filter for preselection, a SAW filter, and a low noise amplifier), and a duplexing circuit. Both the transmitter SAW filter and the receiver SAW filter are low–loss filters with a center frequency of 1.684 GHz, a fractional 3 dB–bandwidth of 3.5 %, and an insertion loss of 6 dB. Pin–diode switching is used in the duplexer. The front–end operates at 1.684 GHz and has a 1 dB–bandwidth of 30 MHz. The output power at the antenna port is 23 dBm. The transmitter–receiver isolation is better than 50 dB. The present work arose from a requirement of a minature low–cost front–end for the digital European cordless telephone. The paper also presents some new design techniques for low–loss SAW filters in the upper UHF band.

INTRODUCTION

The recently developed radio communication systems in the low–GHz range (e.g. the global positioning system GPS, the digital European cordless telephone DECT, the personal communication network (PCN) system DCS1800 as well as planned radio communication systems) are characterized by a high complexity both in the analog system parts and the digital signal processing parts. The analog system parts require miniaturized high–performance active and passive components. Table 1 summarizes the system requirements for modern RF filters. The frequency range of contemporary surface–acoustic–wave (SAW) devices spans 10 MHz to 3 GHz, which encompasses a very desirable frequency range for modern RF filtering and signal processing. The SAW technology generally results in system implementations that have smaller size, lower weight, lower cost and lower power consumption than previous systems. These features are very important in ongoing trends towards implementing portable configurations of consumer, commercial and military electronics (1).

Last year, we presented a miniature antenna–duplexer in the 900 MHz band for the use in the European D–net (2). The fundamental experiments in this work demonstrate the feasibility of the combination of SAW and microstrip technologies for the development of low–cost mobile radio transceiver units. The present work deals with a SAW microstrip front–end at 1.7 GHz which has been designed for the use in the digital European cordless telephone system. The block diagram of the front–end is schematically shown in Fig. 1. The front–end consists of a transmitter final stage SAW filter, two driver amplifiers, a final stage amplifier, a pin–diode duplexing circuit, a receiver top stripline filter, a low noise amplifier, and a receiver second SAW filter. A novel dual–track SAW filter design incorporating interdigital transducers (IDT's) for track–coupling has been used. The device is suitable for low–loss operation and is fabricated with a newly developed submicron photolithography for low–cost pattern mass–production (3).

	Requirements	Reason	
1.	low insertion loss	S/N ratio	(Rx)
		power consumption	(Tx)
2.	high selectivity	preselection	(Rx)
		image frequency suppression	(Rx)
		noise suppression	(Tx)
		spurious signals rejection	(Tx)
3.	miniaturization	volume and weight reduction	
4.	low temperature coefficient, reproducibility and reliability	system performance	
5.	low cost	system cost	

Table 1 System requirements for modern RF filtering; (Rx): receiver part, (Tx): transmitter part

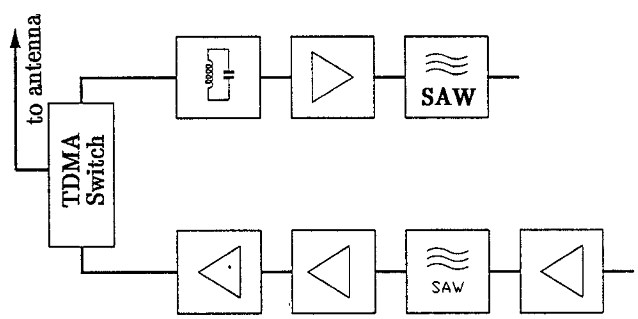

Figure 1 Block diagram of SAW antenna–duplexer

LOW–LOSS SAW FILTERS

Conventional SAW devices have numerous advantageous features such as excellent stopband rejection, sharp cutoff frequency response, good reproducibility and high reliability. However, they suffer from high insertion loss and low operating frequency. In the last years, several SAW filters operating in the GHz range have been presented. They achieve a high center frequency by operating at higher spatial harmonics, so that they can be fabricated by using standard photolithography processes. GHz filters on quartz provide high temperature stability and reliability allowing their use in oscillators and clock recovering circuits (4). However, their high insertion loss of 15 to 25 dB renders them inadequate for front–end stages. On the other hand, numerous low–loss filter techniques have been introduced in the last decade allowing the fabrication of SAW–components with an insertion loss of only a few dB, suitable for front–end stages. The operation frequency is limited due to the inherent increase in losses at high frequencies.

This paper introduces some new design techniques for the development of low–loss filters in the GHz range. In (5), *Hikita et al.* presented a sophisticated interdigitated dual–track configuration which provides a low–loss, low–ripple characteristic by separating the parts of the structure affecting the filter selection and the low–ripple operation. We improved this configuration by using self–suppression mechanisms for echo signals and optimizing the structure pattern by means of accurate simulation models. Fig. 2 shows the SAW filter configuration. The track–coupling occurs by electrically connected interdigital transducer pairs consisting of two identical IDT's each placed in one track. For an appropriate dimensioning of the transducer pattern self–matching occurs, leading to a tight track–coupling within the passband (6). In the stopband, however, the contribution of the electrostatic capacitance of the transducer leads to electrical mismatching and hence to decoupling of the tracks. For symmetrical feeding of the coupling IDT's short uniform IDT's are used, which also determine the filter impedance. Reflective strips at the end of the tracks reduce the bidirectional losses. The filter bandwidth is determined by the track–coupling and increases with increasing piezoelectric coupling coefficient k^2. Therefore, crystals with high k^2 are appropriate for RF applications with fractional bandwidths of a few percent. The filter response is given by the total hybrid acousto–electric network including the electric and acoustic connections between the transducer elements. The transducers operate on the fundamental mode to prevent bulk mode radiation losses. Efficient CAD tools have been formulated for filter modelling and synthesis (7).

As a substrate material, lithium tantalate has been used which lies between quartz and lithium niobate in both piezoelectric coupling strength and temperature stability. We use the 36^0 rotated YX–$LiTaO_3$ cut which has a k^2 of 0.066 and a velocity temperature coefficient of –30 ppm/K. The acoustic wave–type has a velocity of 4216 m/s.

Low–loss SAW devices operating in the GHz range require a submicron patterning process. The filters are fabricated by single layer technology and standard photolithography with 10:1 reduction projection printing and lift–off technique. This fabrication process, which is described in detail in (8), yields a high resolution down to 0.4 μm, good reproducibility; and it allows low–cost mass production.

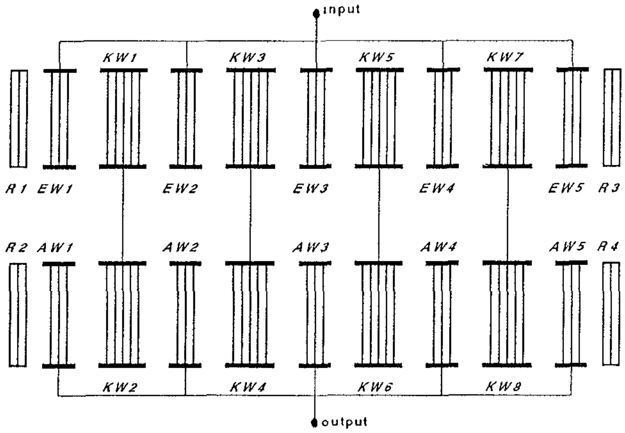

Figure 2 Dual–track low–loss SAW filter

The SAW filter consists of 5 input IDT's, 5 output IDT's, and 4 track–coupling IDT–pairs. Special attention has been paid to the layout design in order to obtain optimum transducer interconnections and low ohmic effects. The minimum electrode width is 0.6 μm, and the chips have a size of 1.9 x 1.9 mm^2 fitting into a modified TO–39 package with 8 pins providing an excellent performance with respect to electromagnetic feedthrough suppression. Fig. 3 shows the measured frequency response of the filter (scaled to 0 dB). The filter has a center frequency of 1.684 GHz and a 3 dB–bandwidth of 3.5 %. The minimum insertion loss is 6 dB and the group delay at center frequency is 53 ns. The passband ripple is ±1.5 dB and ±15 ns, respectively. The stopband rejection is better than 45 dB in the region 100 MHz away from the center frequency. For matching, a shunt inductance of 6 nH at the two electrical ports has been used. The filters are well suited for front–end applications in the receiver for preselection as well as in the transmitter for noise suppression.

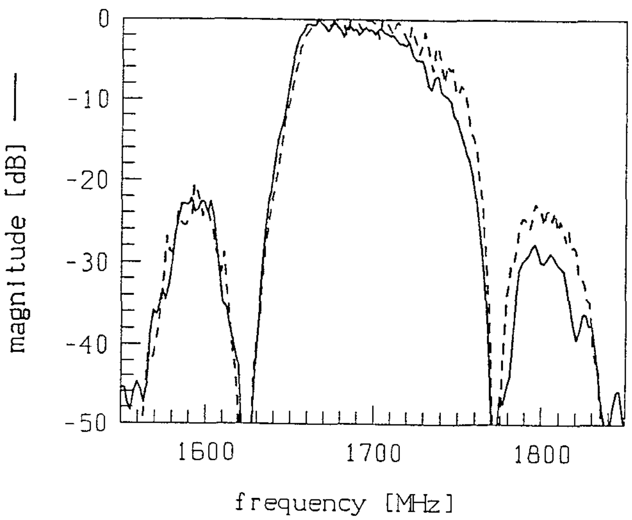

Figure 3 Simulation (– – –) and measurement (——) of SAW filter frequency response

FRONT–END CIRCUIT

The complete front–end has been fabricated on low–cost epoxy ($\epsilon = 4.5$). The layout is shown in Fig. 4. The substrate is 4 x 8 cm² in size. The transmitter consists of two MGF1302 GaAs–FET low noise driver amplifiers, the SAW filter discussed above, and the final stage MGF904 GaAs–FET amplifier. The total gain and the power output are 33 dB and 23 dBm, respectively. The attenuation of harmonics is better than 50 dB at 20 dBm, and better than 40 dB at 23 dBm, as can be seen in Fig. 5. The broadband and narrowband frequency responses of the transmitter (including the TDMA switch) are given in Figs. 6 and 7. The passband ripple is better than 1 dB within 30 MHz. As a TDMA switch, two HP HSMP–3830 low–current pin–diodes have been used (resonant switch). The parasitic elements of the pin–diodes were included in the design. The pin–diode switch has an off–attenuation of 53 dB and an on–mode insertion loss of 1.1 dB. The switch can also be used to control the signal of the antenna. Fig. 8 gives a plot of the measured off–attentuation of the switch. The receiver path consists of a stripline top filter, the MGF1302 FET (noise figure less than 1 dB), and the SAW second filter. Note that the SAW filter is of the same type as is in the transmitter. The frequency response of the stripline filter is given in Fig. 9. As is seen, the attenuation at frequencies below 1 GHz (where most of the commercial cellular radios and television systems operate) is better than 50 dB.

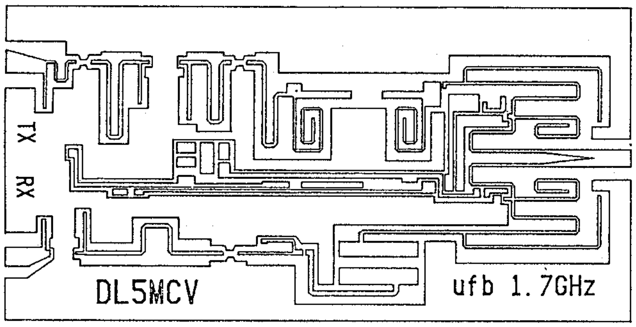

Figure 4 Layout of the front–end

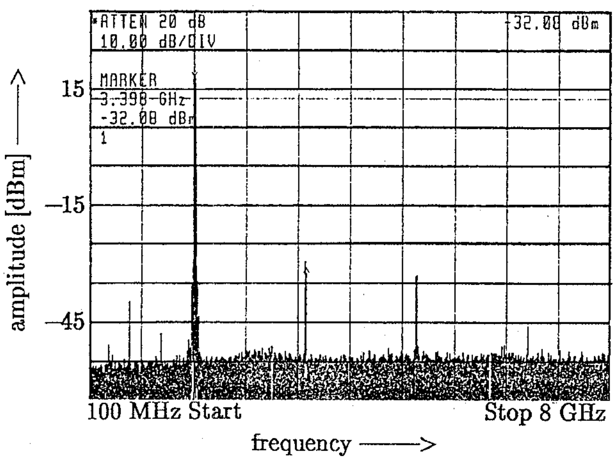

Figure 5 Transmitter power output vs. frequency

Fig. 10 shows the frequency response of the low–current receiver path. The total amplification and the noise figure are 10.3 dB and better than 5 dB, respectively. The receiver is characterized by its high selectivity performance.

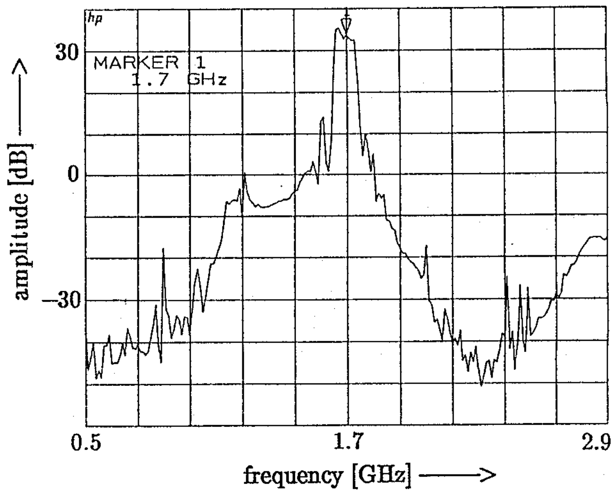

Figure 6 Broadband frequency characteristic of the transmitter

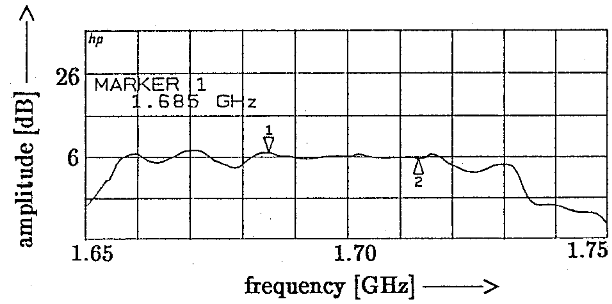

Figure 7 Narrowband frequency characteristic of the transmitter

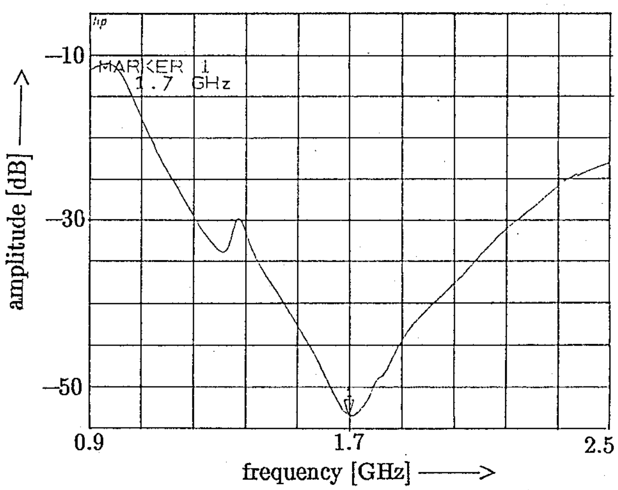

Figure 8 Frequency response of the TDMA switch in off–state

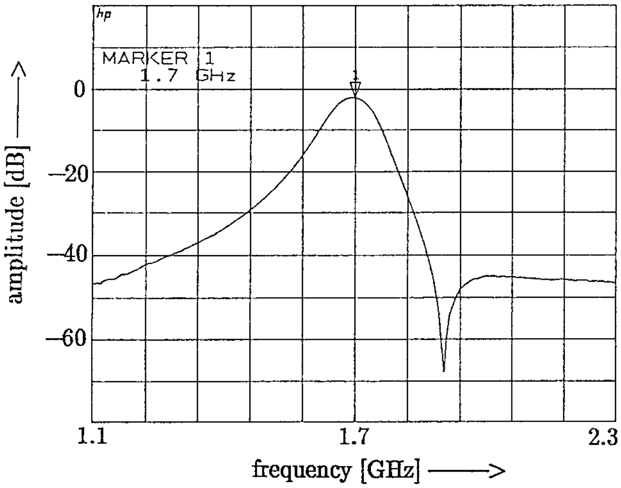

Figure 9 Frequency response of the stripline filter

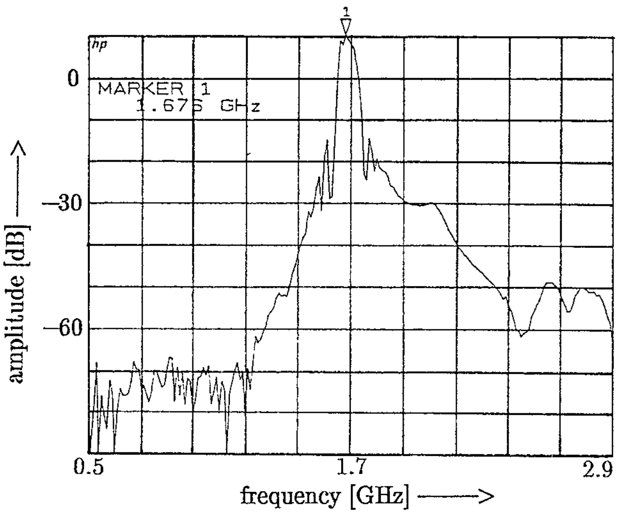

Figure 10 Frequency characteristic of the receiver

CONCLUSION

The work demonstrates the feasibility of the combination of SAW and microstrip technologies for the development of low–cost mobile radio transceiver units. Novel SAW filters have been designed and fabricated for GHz applications. The dual–track technique has been used with the advantage of local separated structure parts responsible for low–loss operation and high selectivity. For fabrication optimized techniques allow a highly reproducible mass–production of the electrode pattern with line widths down to 0.4 μm. The measured filter data exceed results appearing to date in the literature. Our fundamental experiments as well as the current work done to further reduce the insertion loss of SAW filters in the GHz range point the way to numerous new applications of SAW technology in radio communication systems.

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