Recent and future RF SAW technology for mobile communicatins

(Invited)

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Abstract

Surface acoustic wave (SAW) technology has been widely applied to VHF/UHF radio communications to reduce the volume of transceivers. In this paper, not only recent new SAW devices but also future SAW technology to achieve much higher-perfornace devices are investigated. First, the latest status of 0.8-1.5-GHz SAW antenna duplexers for cellular radios and a miniature SAW-VCO are presented. Second, new SAWs with extremely high velocities and fine submicron process techniques are examined. Finally, a future SAW-based chip-type receiver is discussed.

1. Introduction

In radio personal communications, such as cellular-radio and cordless-telephone systems, miniature devices, e.g., SAWs, MMICs, LSIs, etc. are strongly required to reduce the size of transceiver units. An antenna duplexer and an RF/IF voltage-controlled oscillator (VCO) have occupied large circuit areas, because the former is constructed with cascade-connected semi-coaxial resonators and the latter is constructed with MIC or semi-coaxial resonator and discrete transistors, varactor diodes and chip capacitors/resistors.

In this paper, high-performance SAW filters that can dramatically reduce the antenna duplexer size, and a wide-band SAW resonator together with a peripheral-circuit IC that can provide a miniature VCO module are presented. SAW devices applying to future GHz-band communications require new piezo-electric substrates with extremely high-velocity SAWs as well as very fine process techniques. New logitudinal-leaky SAWs on $LiNbO_3$ and a new photo-lithography method with phase-shifting masks are examined for the former and the latter, respectively. Possibility for the large-scale RF-integration combined with SAWs and semiconductors is also invetigated.

2. Antenna duplexers for cellular radios

As shown in Fig.1, an antenna dulpexer consists of two filters (T1 and R1) connected in parallel via appropiate phase-shift elements between the antenna and filters [1]. Low loss as well as high-power characteristics are required for T1. High sidelobe suppression characteristics are required for R1. We have developed new SAW resonator-coupled filters and have achieved very high-performance characteristics by combining both 36° YX-$LiTaO_3$ [2] and 64° YX-$LiNbO_3$ [3] substrates. $LiTaO_3$ with good TCD and rather small k2 provides sharp-cutoff frequency responses, while $LiNbO_3$ with not so good TCD but with large k2 provides wide suppression frequency responses [1] [4].

Examples of the developed duplexer for the analog cellular radios are shown in Fig.2 (T1 and R1 individual structures are shown in Fig.(a) and

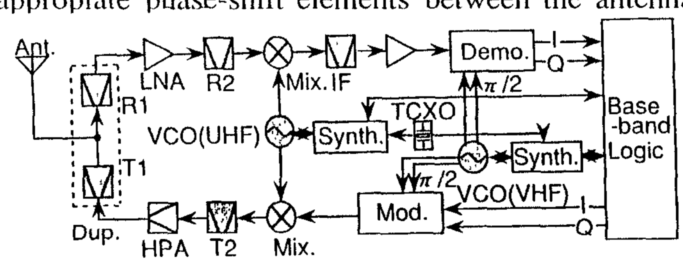
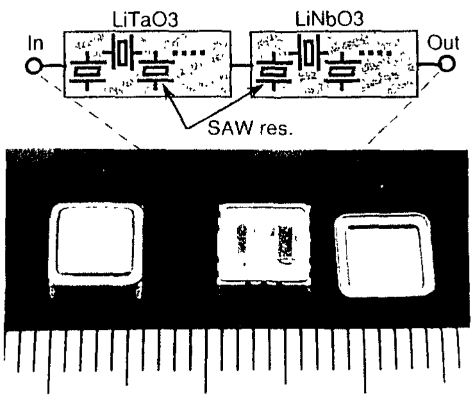
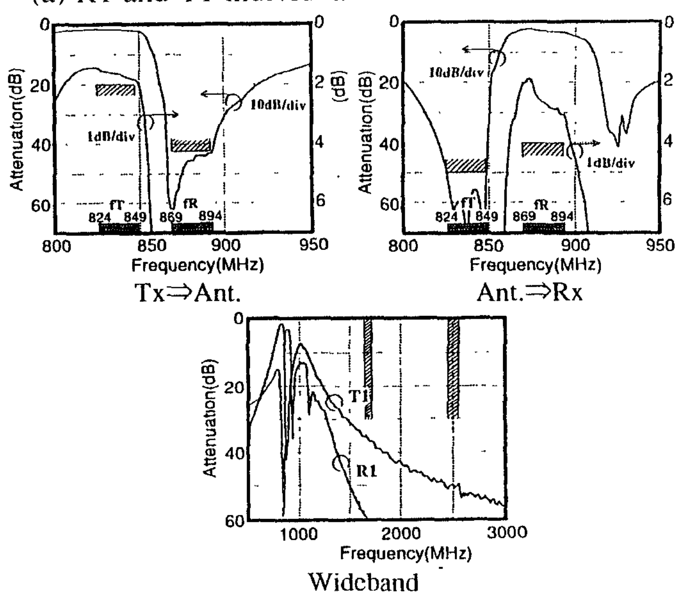


Fig.1 Blockdiagram of radio communications ternimal.



(a) R1 and T1 individual structure.



(b) Frequency characteristics of SAW duplexer.

Fig.2 SAW duplexer for 800-MHz AMPS.

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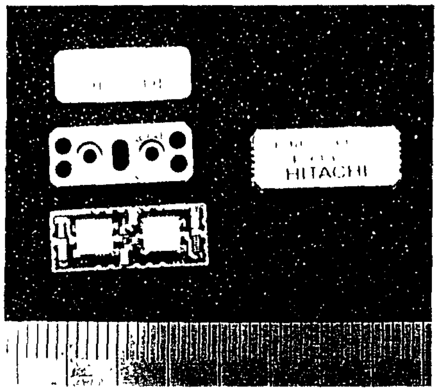
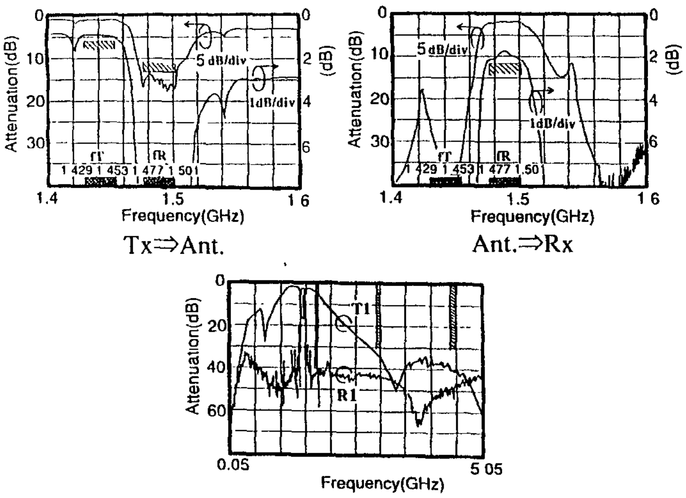
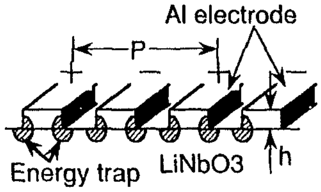


(a) One-module type duplexer structure.

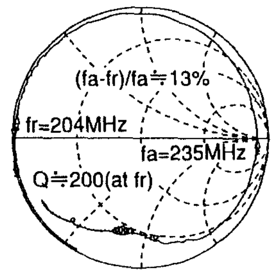


(b) Frequency characteristics for SAW duplexer.
Fig.3 SAW duplexer for 1.5-GHz PDC (digital cellular in Japan).

duplexer frequency responses used in 800-MHz AMPS are shown in Fig.(b)). Low insertion losses as low as 1.9 dB from Tx to Ant. and 3.2 dB from Ant. to Rx, respectively have been achieved. We have also developed one-module type duplexer for the digital cellulars as shown in Fig.3 (duplexer structures are shown in Fig.(a) and duplexer frequency responses used in1.5-GHz PDC are shown in Fig.(b)). Low insertion losses of 1.4 dB fromTx to Ant. and 2.3 dB from Ant. to Rx, respectively have been also achieved. The volume reduction by several times compared with the conventional dielectric-resonator duplexers has been realized. The duplexer thickness is less than 2mm, which is a very important feature required for recent small and thin radio terminals such as card-type terminals, etc..

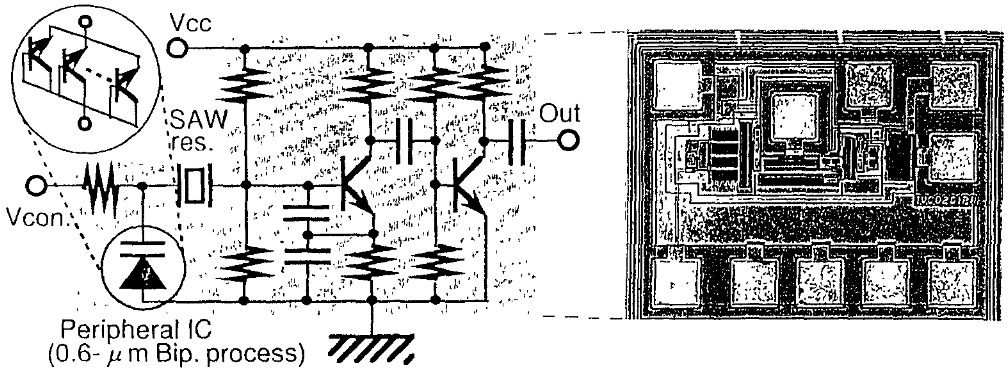


(a) Edge-energy trapped mode (energy is trapped at edges of Al electrodes).

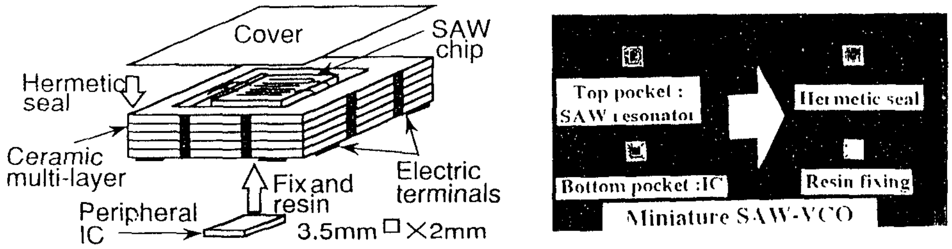


(b) Examples of impedance characteristics for resonator (fr≒200MHz).

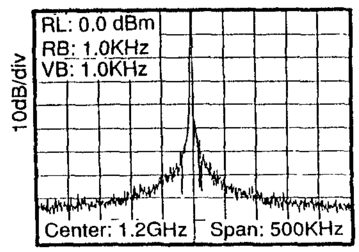
Fig.4 New SAW resonator for VCO.



(a) Equivalent circuit and peripheral IC for VCO.



(b) VCO structure.



(c) Examples of oscillation spectrum for VCO (fo≒1.2GHz).

Fig.5 Minitaure SAW-VCO.

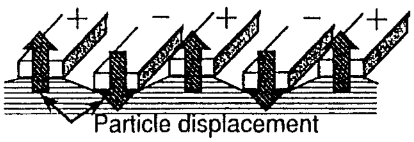
3. Miniature wideband SAW-VCO

As shown in Fig.1, one or two VCOs are used in a radio transceiver. Achieving a wide-frequency variation bandwidth was the most serious problem for SAW-VCOs with high-C/N characteristics [5] . We have found new SAW modes which can propagate along thick Al-electrode grating structures formed on θ(15°)-rot. YX-LiNbO3, as shown in Fig.4(a) [6] . These modes are very similar to Love waves propagating along Au-electrode gratings [7] . The difference is that the former can not exist along uniform Al film on the above LiNbO3, while the latter can propagate along uniform Au film on LiNbO3. Thus, we named these types of SAW "edge-energy trapped mode". The relative bandwidth between fr and fa of the SAW resonators using these modes is 12-14% as shown in Fig.4(b), which is several times larger than the resonators using conventional Rayleigh waves.

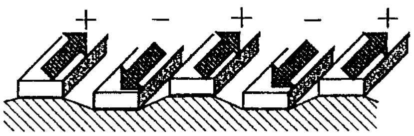
We have also developed a peripheral-circuit IC using 0.6-μm Bipolar-transistor technology, of which equivalent circuit is shown in Fig.5(a). The variable capacitance is made by the depletion-layer capacitances between Emitters and Bases of transistors with backward bias. The miniature prototype SAW-VCO is shown in Fig.5(b). The SAW resonator is mounted within a pocket of the upperside of the SMD package and hermetically sealed. The peripheral IC is fixed within the reverse side pocket and resined. Eletrical terminals are also formed on the reverse side. The module is 3.5 × 3.5 × 2.0mm, which achieves several times volume reduction compared with the VHF/UHF conventional VCOs. This SMD package is commonly usable for 0.2-2.0-GHz SAW-VCOs. The examples of the oscillation spectrum at 1.2 GHz are shown in Fig.5(c), of which C/N must be improved by the next design. These experimental results show the farther possibility of RF circuit integration by combining SAW and IC technology.

4. New SAWs with high velocities and fine lithography techniques

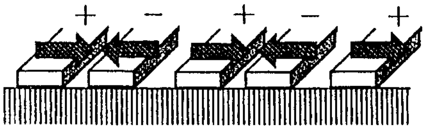
As shown in Fig.6(a) and (b), two types of SAW have been used in SAW filters, i.e., Rayleigh waves for TV-IF filters and SH-type leaky waves [2] [3] for filters to mobile communications [1] . Recently,



(a) Rayleigh waves.



(b) SH-type leaky waves.

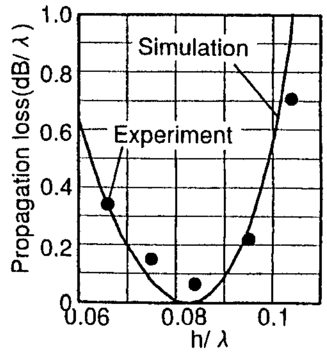


(c) Longitudinal-type leaky waves.

Fig.6 Three types of SAW ((a),(b):conventional SAWs, (c):new SAW).

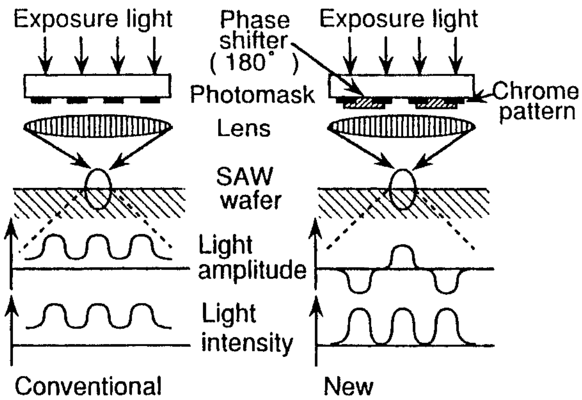
	Vs(m/s)	k^2(%)	TCD (ppm/°C)
128°YX-LiNbO3 (Rayleigh wave)	3901	7.3	80
64°YX-LiNbO3 (SH-leaky wave)	4419	14.5	79
171°YX-LiNbO3 (Longitudinal-leaky wave)	6172	13.3	95

(a) Comparison (Vs:velovity, k2:electro-mechanical coupling coefficient, TCD:temperature coefficient of delay).

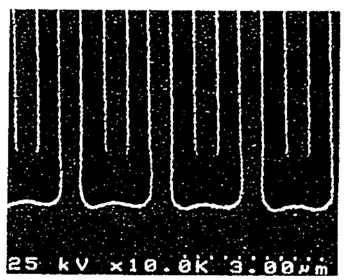


(b) Optimal Al-electrode thickness for longitudinal-type leaky waves.

Fig.7 Comparison between conventional and new SAWs in LiNbO3.



(a) Conventional and phase-shift method.



(b) 0.4-μm Al-electrodes and spaces.

Fig.8 New fine photo-lithography technique.

longitudinal-type leaky waves with the higher velocities have been found on Li2B4O7 with special cut angles [8]. Schematic illustrations of the new SAWs are shown in Fig.6(c). Later, we have also found same types of SAW on θ (171)-rot. YZ-LiNbO3 [9] [10]. Features of of these new SAWs are summarized in Fig.7(a) compared with other two types of SAW on LiNbO3. The velocity is largest in almost all cuts of LiNbO3. However, the smallest propagation losses can be obtained only within the limited range of IDT Al-electrode thickness, as shown in Fig.7(b).

We have used the i-line 1/10-photo-reduction printing with phase-shifting masks shown in Fig.8(a) to high-frequency SAW devices, because IDTs have periodic structures, therefore the phase-shift method can be most effectively applied [11]. 0.4-μm Al electrodes and also 0.4-μm spaces made by the above method are shown in Fig.8(b), which correspond to about 2.5-GHz filters if using Rayleigh waves and about 3.9-GHz filters if using the longitudinal-leaky waves. SAWs with extremely high velocities as well as fine lithography techniques are essentially important for the future GHz-band SAW devices. These experimental results show that SAW technology can be applicable not only to recent 0.8-2.0-GHz mobile communications but also to future several GHz-band mobile communications.

5. Future SAW device trends

Monolithic integration technology will be very important in the future. Especially, RF system-on-chip devices including both active- and passive-circuit elements will be one of our goals to achieve the smallest radio terminals. As shown in Fig.9, an epitaxial Si film formed on a piezo-electric substrate may provide very attractive monolithic ICs, which lead to large-scale RF integration. We are examining not only Si hetero-epitaxial technology but also heat-press-contact techniques [12] to form the compound materials, such as very thin Si film on non-semiconductor substrates. The active circuits, e.g., LNA, Mix., feedback amplifier of VCO, etc. are formed on the Si film, while the passive circuits, e.g., filters, resonators, RF signal processors, etc. are formed on the piezo-electric substrate. Many problems must be solved to achieve Fig.9's such one-chip receiver. However, by the beging of 21st century the founten-pen or wrist-watch types radio terminal will appear using the above technology.

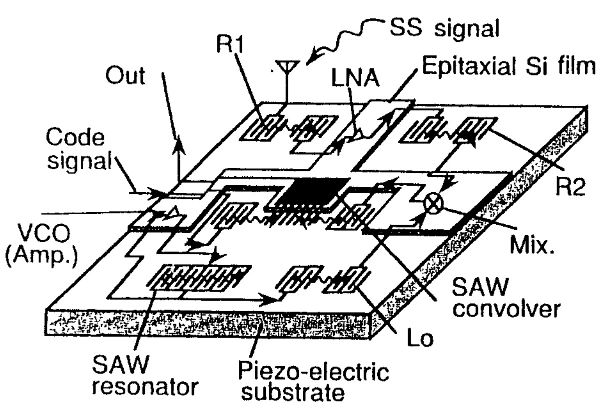


Fig.9 Future chip-type receiver using SAW technology.

6. Conclusion

The provision of voice and data to peaple who are moving about or away from their wireline terminals have been required as one of the major communication means. The future goal for such wireless communications will be to provide higher-quality services with lower-power and smaller-sized radio telephones and data terminals. In this paper, we showed that SAW technology together with monolithic-IC technology would be continued to offer key devices for such future mobile communications.

REFERENCES

1. M.Hikita, N.Shibagaki, K.Sakiyama, and K.Hasegawa, "Design methodology and experimental results for new ladder-type SAW resonatot coupled filters," IEEE Trans., UFFC-42, pp.495-508, 1995.
2. K.Nakamura, M.Kazumi, and M.Shimizu, "SH-type and Rayleigh-type surface wave on rotated Y-cut LiTaO3," in IEEE Ultrason. Symp. Proc., 1977, pp.819-822.
3. K.Yamanouchi and K.Shibayama, "Propagation and amplification of Rayleigh waves and piezoelectric leaky waves in LiNbO3," J.Appl.Phys., vol.43, pp.856-862, 1972.
4. M.Hikita, A.Isobe, A.Sumioka, N.Matsuura, and K.Okazaki, "Rigorous treatment of leaky SAW's and new equivalent circuit representation for interdigital transducers," IEEE Trans. UFFC-43, pp.482-490, 1996.
5. M.Hikita, A.Sumioka, and T.Tabuchi, "A wideband SAW resonator and its application to a VCO for mobile radio transceivers," IEEE Trans. VT-43, pp.863-869, 1994.
6. A.Isobe, M.Hikita, C.Takubo, and K.Asai to be published in Proc. '97 IEICE Spring Conf. in Japan, 1997.
7. H.Shimizu, Y.Suzuki, and T.Kanda, "Love-type-SAW resonator of small size with very low capacitance ratio and its application to VCO," in IEEE Ultrson. Symp. Proc., 1990, pp.103-108.
8. T.Sato and H.Abe, "Propagation properties of longitudinal leaky surface waves on lithium tetraborate," in IEEE Ultrason. Symp. Proc., 1994, pp.287-292.
9. A.Isobe, M.Hikita, C.Takubo, and K.Asai, "Longitudinal leaky SAW-resonator in LiNbO3 - the combined finite-element and analytical method -," in Proc. '96 IEICE Autumn Conf. in Japan, 1996, vol.A-195.
10. A.Isobe, M.Hikita, C.Takubo, and K.Asai, "Analysis of longitudinal leaky SAW in LiNbO3 using the combined finite-element and analytical method," in 17th Ultrason. Electron. Symp. in Japan, 1996, pp.331-332.
11. K.Asai, A.Isobe, T.Tada, and M.Hikita, "SAW timing-extraction filter and investigation of submicron process technology for Gb/s optical communications system," in IEEE Ultrason. Symp Proc., 1995, pp.131-135.
12. K.Asai and M.Hikita, Japanese Patent to be filed.