TWO-PORT SAW RESONATOR UTILIZING PIEZOELECTRIC SURFACE SHEAR WAVE MODE

Yasuaki Kinoshita, Hiroomi Kojima and Toyoharu Tabuchi
Central Research Laboratory, Hitachi Ltd.
Kokubunji, Tokyo, 185 JAPAN

ABSTRACT

Piezoelectric Surface Shear Wave (SSW) and its reflections at $LiNbO_3$ substrate edges, have been newly utilized for two-port resonators. The resonator of SSW mode exhibits a broader bandwidth compared with Rayleigh mode resonators.

Introduction

It had been considered that the use of substrate edge reflections for a surface acoustic wave (SAW) resonator was not adequate because of the mode conversion from SAW to bulk wave.[1] Fractional bandwidths (0.01 ~ 2%) of Rayleigh wave resonators[2,3] are restricted by the frequency selectivity of the grating reflectors placed on the substrates.

Recently, piezoelectric surface shear wave (SSW) mode have been utilized for SAW resonators which have employed reflection edges of a substrate whose electromechanical coupling coefficient of the SSW mode is very large, and which have exhibited broad resonance characteristics.[4,5] One-port SSW resonators[5] of the unloaded Q = 200 ~ 500 have been achievable on $LiNbO_3$ substrates with the practical thicknesses of 5 ~ 8 wavelengths.

Two-port resonators having reduced spurious responses associated with edge reflectors have been described in this paper. This new structure is an extension of one-port resonators,[4,5] in which the spurious resonances are completely suppressed. Filters of 3 ~ 4.5% fractional bandwidths with low insertion losses under 6 dB have been obtained by cascading these two-port $LiNbO_3$ resonators.

SSW Mode One-Port Resonator

The theoretical existence of SSW has been well known as Bleustein-Gulyaev-Shimizu wave (BGSW).[7,8,9] Recently, experimental investigations on a SSW resonator as shown in Fig. 1 have been reported.[4,5] The input admittance of the resonator is given by the admittance matrix element Y_{33} of the Smith's model.[6] The one-port resonator consists of an assembly of unit resonator cell of the same periodic section, as shown in Fig. 1. Using the crossed-field model[6] and introducing a loss resistance R_1, the unloaded Q of the resonator is given by[5]

$$Q = \pi^2/(8R_1\omega_0 C_s N k^2) \qquad (1)$$

where C_s is the static capacitance of the electrode finger pair, N the numbers of the periodic sections, and $\omega_0 = 2\pi v/L$. Coupling coefficient k^2 is given by the measured frequencies of the series and parallel resonance of the resonator,[5] as shown in Table 1.

Table 1. Unloaded Q and k^2 of one-port resonators (L = 184 μm)

substrate	frequency (MHz)	measured k^2	unloaded Q
$LiNbO_3$ 64°Y-X	25	0.08	200 ~ 500
$LiNbO_3$ 41°Y-X	25	0.12	250
ceramics	13	0.03 ~ 0.05	70 ~ 200

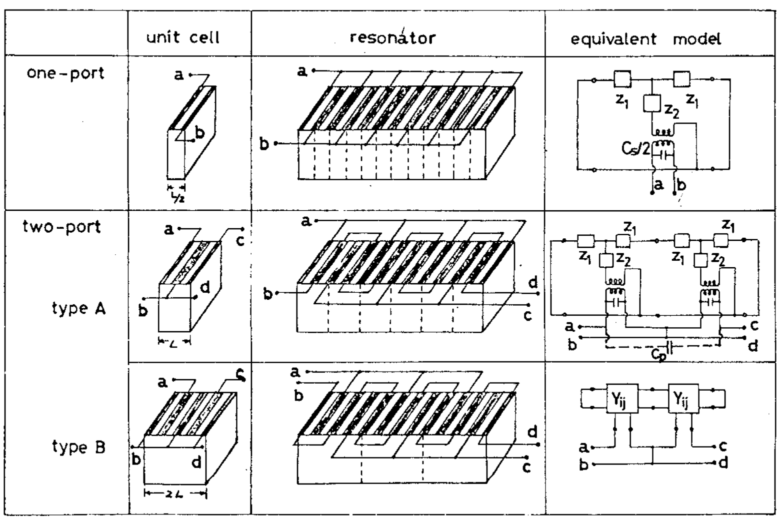

Fig. 1. Two-port resonators consisting of assemblies of unit resonator cells and their equivalent circuit models.

SSW Displacement Field in Resonator

SSW on a ceramics substrate is known as BGSW.[7,10] SSW on a $LiNbO_3$ rot. Y-X prop. substrate is a family of leaky elastic surface wave,[10] and has the residual components of the displacement u_1 and u_2 in Fig. 2. The theoretical amplitude decay of BGSW displacement u_3 toward x_2 axis in Fig. 2, is very fast under the metallized surface of the substrate whose k^2 is very large, but the decay is very much slow under the free surface. The decay of SSW under the surface on which an interdigital transducer (IDT) is placed is a very interesting problem.

As an investigation of this problem, the dependence of Q upon the substrate thickness of the one-port resonator has been experimented, and it is concluded that SSW field are effectively confined within 5 ~ 8 wavelengths from the IDT on the $LiNbO_3$ substrate.

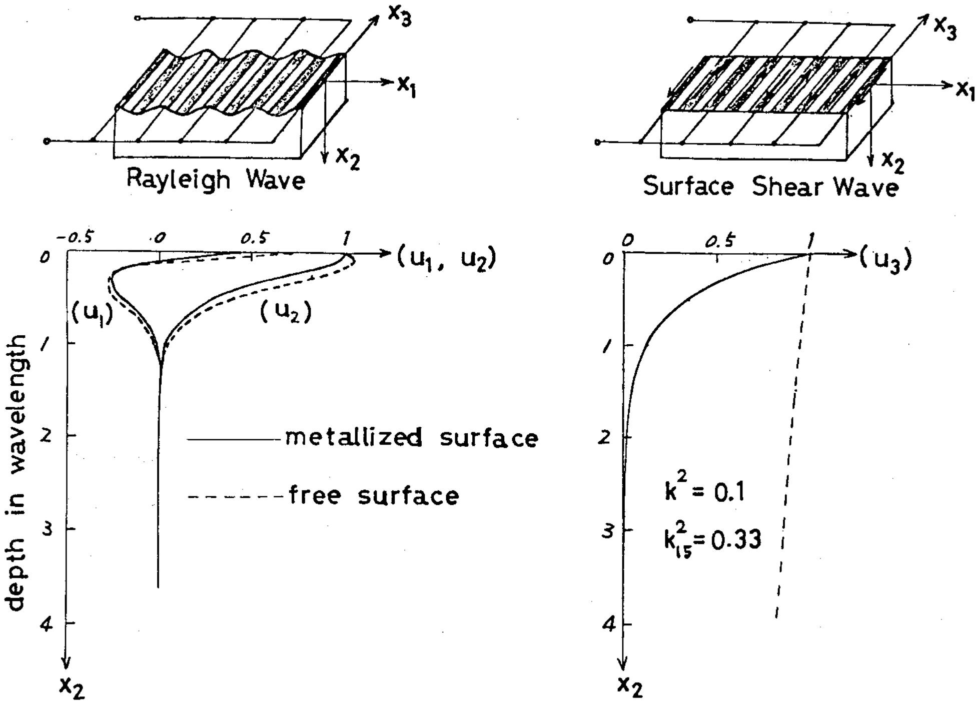

Fig. 2. The decay of SSW (BGSW in this case) displacement amplitude (u_3). For comparison, the decays of Rayleigh wave's (u_1 and u_2) are shown for a ceramics substrate.

Two-Port Resonator

Two-port resonators employing two reflection edges and two IDT generate inevitable spurious responses.[5] A new structure of a two-port resonator can be considered as an extension of one-port resonator as shown in Fig. 1. The resonator is also divided into an unit resonator cell. The transducer electrode of the resonator can be placed on a substrate without the multi-layer connection.

The image propagation constant $\phi(\omega)$ of the resonator is given by

$$\tanh \phi(\omega)/2 = \sqrt{Y_f/Y_s} \qquad (2)$$

where $Y_s = j\omega C_s/2 + j2G_0 \tan\theta/4$, $Y_f = j_2\omega C_s/2 + jG_0 \tan\theta/2$, $\theta = 2\pi\omega/\omega_0$, and $G_0 = \omega_0 C_s k^2/2\pi$. The calculated attenuation constant is shown in Fig. 3(a). The measured response is also shown in Fig. 3(b), where a $LiNbO_3$ 64^oY-X substrate is used. To improve the equivalent model, a static capacitance C_p is added in Fig. 1. The calculated response of dashed line in Fig. 3(a) is in agreement with the measured one in Fig. 3(b).

Filter Using Two-Port Resonators

To realize a SAW filter of cascaded two-port resonators, another two-port resonators having different spurious frequencies are necessary for the spurious suppressions. One of the useful two-port structure is shown in Fig. 1 as type B. The calculated and experimented frequency response are shown Fig. 4(a) and 4(b). The numbers of the spurious responses increased compared with the type A.

Fractional bandwidths Δ of these type A and B resonators are given by

$$\Delta = (2/\pi)^2 k^2 = 0.405\, k^2. \qquad (3)$$

This bandwidth by the image parameters shows good agreement with the measured values of the cascaded resonators.

As an example of SSW mode filters, experiments are shown in Fig. 5(a) and 5(b). A fractional bandwidth of 3 ~ 4.5% has been obtained by using $LiNbO_3$ substrates.

Conclusions

A SSW filter having a broad bandwidth and a low insertion loss is obtainable on a single substrate with two reflection edges. Use of an equivalent model by Smith[6] is very useful for the analysis of the interactions between SSW and IDT.

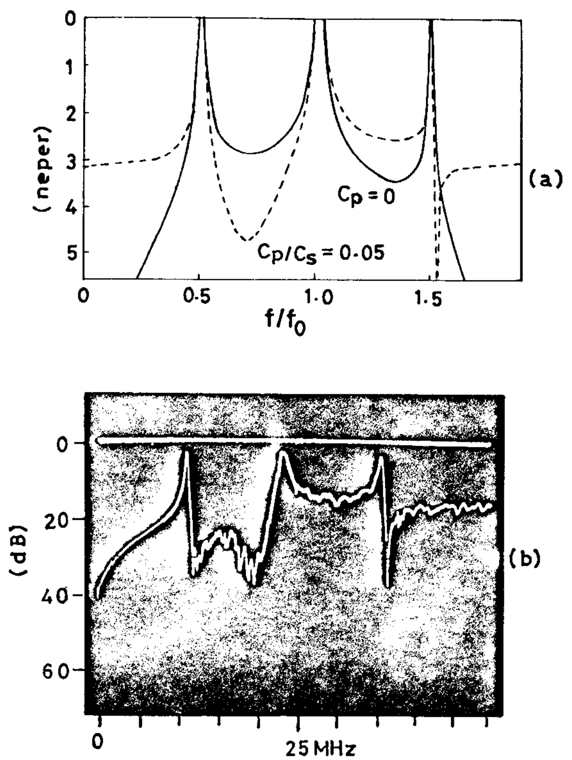

Fig. 3(a) The image attenuation constant of the type A two-port resonator shown in Fig. 1.
(b) The measured frequency response of the two-port resonator.

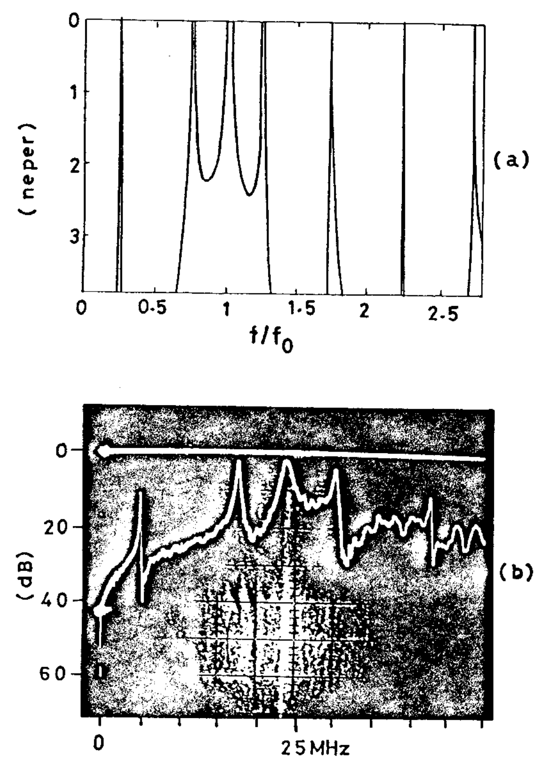

Fig. 4(a) The image attenuation constant of the type B resonator.
(b) The measured frequency response of the resonator.

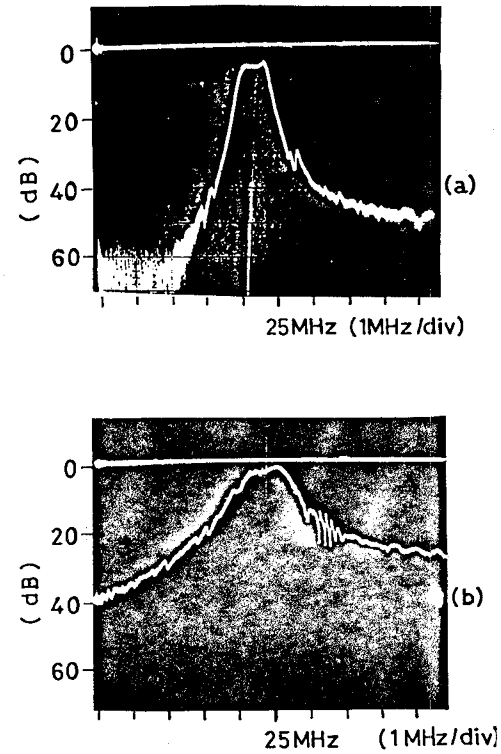

Fig. 5. Frequency responses of SSW filters of cascaded two-port resonators. (a) type A - type B - type A resonators of $LiNbO_3$ 64°Y-X substrates. (b) type A - type A resonators of $LiNbO_3$ 41°Y-X substrates.

References

1. E. A. Ash: 1970 IEEE G-MTT International Microwave Symposium Digest, p. 385.
2. W. R. Shreve: 1976 IEEE Ultrasonics Symposium Proc., p. 706.
3. F. Sandy and T. E. Parker: ibid., p. 391.
4. Y. Suzuki, H. Shimizu, M. Takeuchi, K. Nakamura and A. Yamada: ibid., p. 297.
5. Y. Kinoshita, H. Kojima and T. Tabuchi: Proc. of the first Meeting on Ferroelectric Materials and Their Applications at Kyoto (Nov. 1977).
6. W. R. Smith, H. M. Gerard, J. H. Collins and T. M. Reeder: IEEE Trans., vol. MTT-17 (Nov. 1969) p. 859.
7. J. L. Bleustein: Appl. Phys. Lett., vol. 9 (15 Dec. 1968) p. 412.
8. Yu. V. Gulyaev: Soviet Phys. JETP Lett., vol. 9 (Jan. 1969) p. 37.
9. Y. Ota, K. Nakamura and H. Shimizu: Paper of the Tech. Group on Ultrasonics IECE Japan (in Japanese) vol. US 69-3 (1969).
10. A. Takayanagi, K. Yamanouchi and Shibayama: ibid., vol. US 70-1 (1970).