A Bleustein–Gulyaev–Shimizu Wave Resonator Having Resonances for TV and VCR Traps

Michio Kadota, Junya Ago, and Hideya Horiuchi

***Abstract*—A Bleustein–Gulyaev–Shimizu (BGS) wave has only a shear horizontal (SH) wave showing a complete reflection at a free edge of a substrate. By utilizing this property, a small BGS resonator having one resonance without reflector electrodes is realized. In this paper, using the responses exited by a weighted interdigital transducer (IDT) and generated by the $2N\pm 2$th mode's complete reflections at free edges of a ceramic substrate, we realized a new type of BGS resonator having resonances without reflector electrodes. This resonator showed sufficient trap attenuations for practical use at both adjacent picture carrier frequency (f_{ap}) and adjacent sound carrier one (f_{as}) in the TV and VCR video intermediate frequency (VIF) circuit.**

I. Introduction

A BLEUSTEIN-GULYAEV-SHIMIZU (BGS) wave propagating on a piezoelectric ceramic substrate polarized parallel to its surface has only a shear horizontal (SH) displacement. The SH wave shows a complete reflection at a free edge of the ceramic substrate [1], [2]. A Rayleigh surface acoustic wave (SAW) type resonator requires reflectors with a lot of fingers. While, by utilizing this reflection of the BGS wave at the free edges, a very small resonator without reflector electrodes is realized. So far, the BGS wave resonator using a ceramic substrate has not been investigated for practical applications because of the difficulties in poling the large ceramic substrate parallel to its surface and developing a ceramic substrate with both large electromechanical coupling factor and small temperature coefficient.

We have succeeded in solving these problems and in developing the free edge reflection type BGS wave resonator with only one resonance, using a ceramic substrate (PZT: $Pb(Ti,Zr)O_3$) for the first time in the world, which was characterized by its super miniature (its size $\leq 1 \times 1 \times 0.5$ mm), wide band ($\geq 5\%$) characteristic and no-frequency-adjusting in 20 to 160 MHz [2], [3]. The BGS wave resonators in the 30 to 60 MHz frequency range have been widely used as additional trap resonators in video intermediate frequency (VIF) circuits in TV and VCR (VTR) sets, taking the place of LC resonators requiring frequency-adjusting in the use [2]. The additional trap is effective especially in the European sets where TV channels are close and in the US sets which have numerous CATV channels, in order to avoid the influence of adjacent picture carrier (f_{ap}) or adjacent sound carrier (f_{as}). Two kinds of trap resonators are required for the additional traps at f_{ap} and f_{as} as shown later in Fig. 7. At present, these two kinds of resonators are separately designed, produced and supplied to the market.

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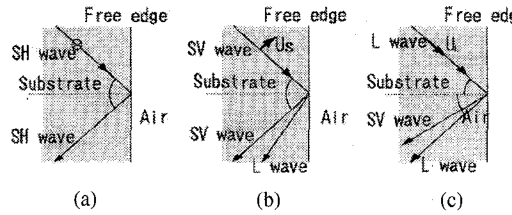


Fig. 1. Reflection properties of elastic wave at a free edge.

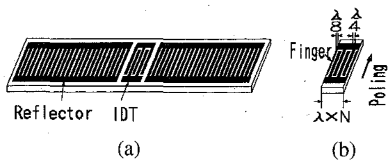


Fig. 2. (a) Rayleigh SAW resonator with reflector electrodes. (b) BGS wave resonator utilizing free edge reflections.

The above-mentioned BGS resonator using the free edge reflections has only one resonance without spurious responses. In this paper, we propose a resonator with three resonances for both the f_{ap} and the f_{as} traps, obtained by applying responses generated by a weighted interdigital transducer (IDT) and by $2N \pm 2$th mode reflections at the free edges.

II. A BGS Wave Resonator with Only One Resonance Using Free Edge Reflections

The BGS wave propagating on a piezoelectric ceramic substrate polarized parallel to its surface has only an SH component. On the other hand, a Rayleigh wave has a longitudinal (L wave) and a shear vertical (SV wave) components. Fig. 1 shows their reflection properties at a free-edge of the substrate. As shown in Fig. 1, the SH wave such as the BGS wave undergoes complete reflection at a free-edge of a substrate with high dielectric constant. On the contrary, the Rayleigh SAW wave having a longitudinal and a shear vertical components has not this property because the longitudinal and the shear vertical components are, respectively, converted to both longitudinal and shear vertical components at the free edge. A very small size BGS wave resonator is realized without reflector electrodes by using this free-edge reflection. In comparison the Rayleigh SAW wave resonator requires reflectors with many electrodes. Fig. 2 shows these resonators. A BGS wave resonator with one resonance utilizing the free edge reflections has a normal IDT with fingers of width $\lambda/8$

and $\lambda/4$ (λ is the wave-length in the IDT) as shown in Fig. 2(b). The width of edge finger must be $\lambda/8$ and the distance L between the two edges must be $N \times \lambda$ (N is the number of finger-pairs in the IDT). Solid and broken lines in Fig 3(a) show a frequency spectrum of the resonator with N finger-pairs normal IDT and one determined by the distance L, respectively. In this device, the odd modes ($2N \pm 1, 3, 5, \cdots$th modes) and the even modes ($2N \pm 2, 4, 6, \cdots$th modes) are not excited by the IDT because the odd modes are canceled by the IDT's symmetry and the even modes coincide with the nulls of the frequency response of the IDT. Therefore, the fundamental resonant frequency of the resonator is generated only by the $2N$th mode as shown in Fig. 3(b) [1], [2]. When the distance L between the two free edges is different from $N \times \lambda$ or the free-edge has large chipping, the even mode responses are generated because their frequencies are away from the nulls of the frequency response of the IDT. Fig. 4 shows a principle which the even mode responses are generated because $L \neq N \times \lambda$. Fig. 5 shows examples for which the $2N - 2$th even mode response is not generated [Fig. 5(a)] and is generated [Fig. 5 (b)]. In Fig. 5(a), the $2N - 4$th and $2N - 2$th even modes are not generated because $L = N \times \lambda$. In Fig. 5(b), these modes are generated at 37.3 MHz and 38.6 MHz because $L \neq N \times \lambda$ ($L = N \times \lambda + \lambda/10$). In both figures, the resonant frequencies at 40.4 MHz are the $2N$th modes of the main response. The difference Δf between the resonant frequency f_r and the antiresonant one f_a (= 42.5 MHz) was large (2.1 MHz: $\Delta f/f_r$ = 5%), the capacitance was 18 pF and the capacitance ratio was 8.5 because of the large electromechanical coupling factor. The spurious response caused by the transverse mode between f_r and f_a were of no consequence for the additional trap application as shown later in Fig. 7. The resonator for the additional trap is required a suitable capacitance value to meet electrical matching requirements. Because the PZT ceramic substrate has a large dielectric constant, merely adjusting the number of IDT fingers and the width of the aperture can not reduce to the required capacitance value. Therefore, the IDT was divided into two parts which were connected in series as shown in Fig. 6 (see an enlargement above in this figure). The finger pairs of the IDT was 15.5, the aperture was 340 μm, and wavelength was 58.4 μm. The PZT ceramic substrate developed for the BGS wave has many advantages such as a large electromechanical coupling factor (0.47), a small temperature coefficient (9ppm/°C), a large reflection coefficient, a low cost, and less chipping caused by dicing. So, the very small size BGS resonator with wide band and without reflector electrodes and spurious is realized. We already developed BGS resonators with one resonance for additional traps in TV and VCR VIF [2]. Fig. 6 shows very small elements (and their enlargement) after dicing the substrate and the epoxy-resin-packaged BGS wave resonators. Fig. 7 shows the VIF characteristics for the European PAL system with and without the BGS wave resonator having one resonance in a VIF test circuit as shown in Fig. 13(b). The attenuation at f_{as} is improved 20 dB by applying the BGS resonator. When the improvement of attenuation at f_{ap} is required, then another BGS resonator with resonance at f_{ap} is used.

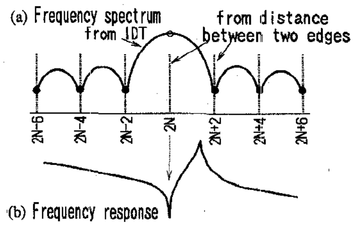


Fig. 3. Frequency spectrum and characteristic of a free edge reflection BGS wave resonator with only one resonance.

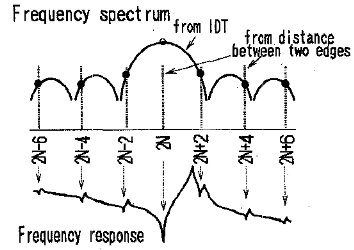
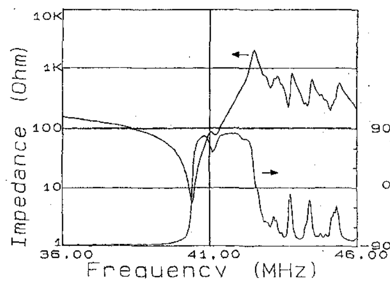
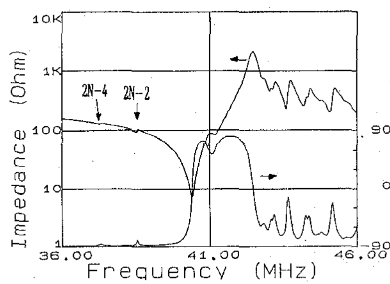


Fig. 4. Even mode responses are generated if $L \neq N \times \lambda$.



(a)



(b)

Fig. 5. Examples of frequency characteristic in which the $2N - 2$th and $2N - 4$th even mode responses (a) are not generated because $L = N \times \lambda$ and (b) are generated because $L \neq N \times \lambda$ ($L = N \times \lambda + \lambda/10$).

III. A BGS Wave Resonator with Multiple Resonances

The frequencies of f_{ap} or f_{as} in the VIF circuits are f_{ap} = 31.9 MHz and f_{as} = 40.4 MHz in the European PAL system, and f_{ap} = 39.75 MHz and f_{as} = 47.25 MHz in the US NTSC system. There exist a sound carrier f_s, a color carrier f_c, and a picture carrier f_p between f_{ap} and f_{as} as shown in Fig. 7. The resonator with resonances for the f_{ap} and f_{as} traps is also required to generate no spurious responses in this range. In this paper, we investigate a new type of resonator with resonances for both f_{ap} and f_{as} using a BGS wave. Fig. 8(a) and (b) shows schematic illustrations of the principles in order to realize a BGS wave resonator with two

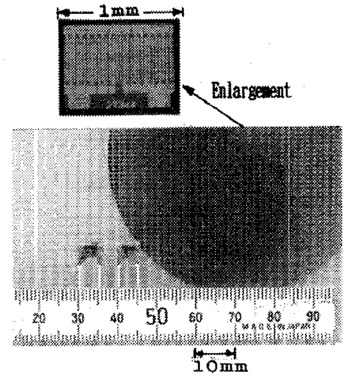


Fig. 6. Elements after dicing and epoxy-resin-packaged components.

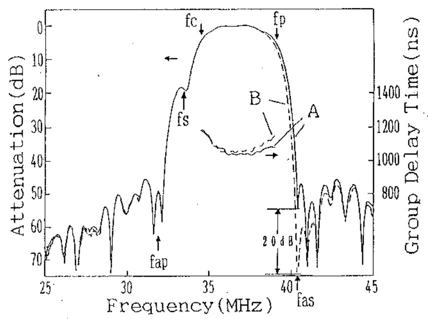


Fig. 7. Frequency characteristics in test circuit of VIF (Solid line: without trap resonator, broken line: with trap resonator).

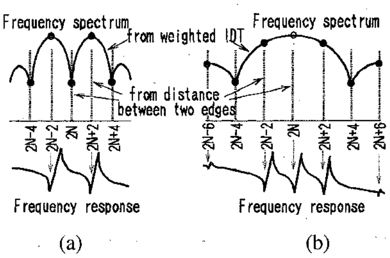


Fig. 8. Principle of operation of a resonator with (a) two and (b) three resonances using BGS wave.

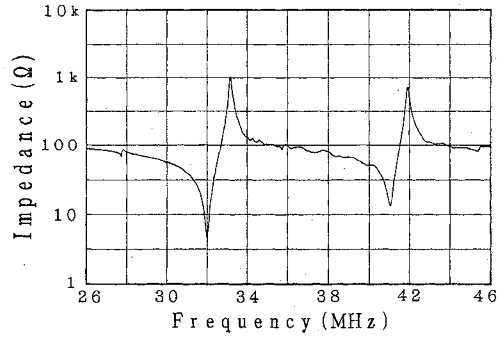


Fig. 9. Frequency characteristic of a resonator with two resonances operating as described in Fig. 8(a).

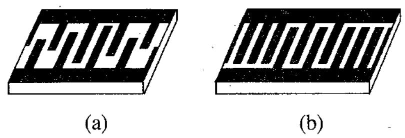


Fig. 10. Examples of (a) apodized IDT and (b) withdrawal weighted IDT to realize a resonator with three resonances described in Fig. 8(b).

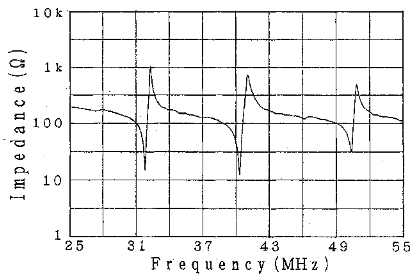


Fig. 11. Frequency characteristic of the BGS resonator with three resonances fabricated with an apodized IDT.

and three resonances, respectively. Solid and broken lines in Fig. 8(a) show the frequency spectrum having two main lobes obtained by weighting an IDT and one determined by the distance between the two edges, respectively. The frequency difference between the f_{ap} and f_{as} is large. Therefore, the limited number of pairs of electrodes must be weighted so that they are not affected by the even mode responses generated by the distance between the edges (depending on the number of finger electrode pairs in the IDT) in the wide frequency range between f_{ap} and f_{as}. In the case of the method described in Fig. 8(a) the finger pair N is defined as $N \approx 2 \times f_{2Nth}/(f_{as} - f_{ap})$. Where f_{2Nth} is $(f_{ap} + f_{as})/2$.N is 8.5 for the European PAL system and 11.5 for the US NTSC system. Taking this into account, we have designed an apodized IDT with $N = 8.5$ having two main lobes and made the main lobes such that they correspond to the $2N \pm 2$th even mode frequencies for the European PAL system. That is, the lower main lobe frequency and the $2N - 2$th mode one correspond to the f_{ap} one, and the higher one and the $2N+2$ mode one correspond to the f_{as} one, respectively. Fig. 9 shows an example of the characteristic of a resonator fabricated using this method. The resonator has two resonances, one at 31.9 MHz for the f_{ap} trap and the other at 40.4 MHz for the f_{as} trap in the European PAL system. Small spurious responses are generated between the f_{ap} and f_{as}, because the attenuation at null response of $2N$th mode based on the apodized IDT was not sufficient. At present it is difficult to get a large attenuation at $2N$th mode and a frequency response without spurious based on $2N$th mode by using the apodized IDT with 8.5 finger pairs, but it is necessary to improve that.

The solid and broken lines in Fig. 8(b) show frequency spectra obtained from the weighted IDT and determined from the distance L between two edges, respectively. Though the $2N \pm 4$th mode responses are canceled because they coincide with the nulls of the IDT's spectrum shown in solid line, the $2N \pm 2$th and $2N \pm 6$th mode responses are generated because they do not coincide with the nulls. In this case, the finger pair N is defined as $N \approx f_{2N\text{th}}/(f_{as} - f_{ap})$: ($N = 4.5$ for the European PAL, $N = 5.5$ for the US NTSC). Where f_{2Nth} is f_{as} and $f_{2N-2\text{th}}$ is f_{ap}. Fig. 10 shows examples of an apodized IDT for the PAL system and a withdrawal weighted IDT for the NTSC system based on

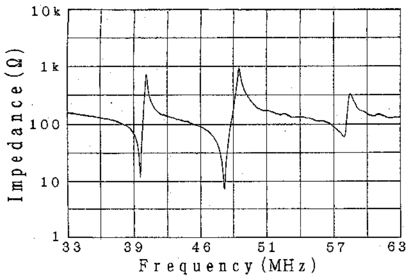


Fig. 12. Frequency characteristic of the BGS resonator with three resonances fabricated with a withdrawal weighted IDT.

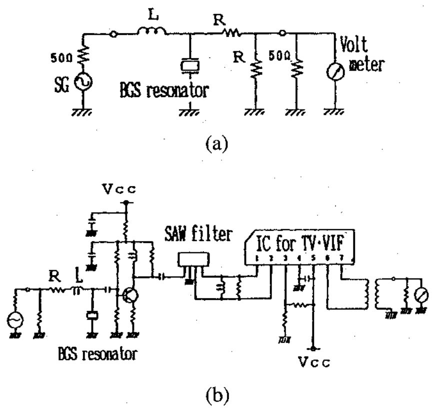


Fig. 13. Test circuits of the trap resonator. (a) Simple circuit. (b) VIF test circuit.

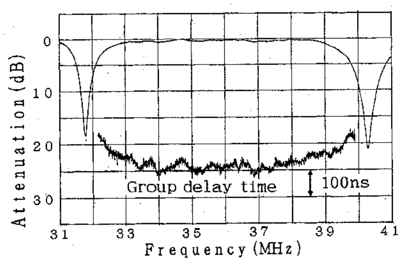


Fig. 14. Frequency characteristic of the BGS resonator with resonances due to the apodized IDT in the test circuit shown in Fig. 13(a).

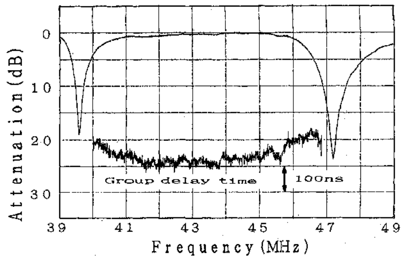


Fig. 15. Frequency characteristic of the BGS resonator with resonances due to the withdrawal weighted IDT in the test circuit shown in Fig. 13(a).

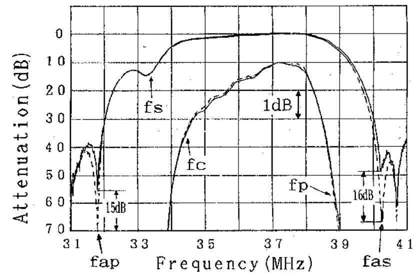


Fig. 16. VIF frequency characteristics in the VIF test circuit shown in Fig. 13(b) (solid line: without the BGS wave resonator, broken line: with the BGS wave resonator).

this principle. Figs. 11 and 12 show impedance characteristics of the BGS wave resonators for the PAL system made with the apodized IDT and for the US NTSC system made with the withdrawal weighted IDT, respectively. In both characteristics, the resonant frequency corresponding to the f_{as} trap is the $2N$th mode's main response of the weighted IDT, and the frequencies corresponding to the f_{ap} trap and above the f_{as} trap are the $2N-2$th and $2N+2$th mode responses generated by the reflections at the free edges, respectively. It is easy to design by the method described in Fig. 8(b) in comparison with that in Fig. 8(a). Because it is very difficult to obtain a sufficient attenuation at the $2N$th mode on the IDT frequency spectrum in Fig. 8(a) by weighting IDT.

IV. Application to Trap Devices

The resonators shown in Figs. 11 and 12 were evaluated as the additional trap at f_{ap} and f_{as} in the simple test circuit shown in Fig. 13(a). Figs. 14 and 15 show the results of the resonators for the PAL and the US NTSC systems, respectively. The trap attenuations are 18 dB at f_{ap} and 21 dB at f_{as} for the PAL system, and 19 dB at f_{ap} and 24 dB at f_{as} for the US NTSC system as shown in these figures. The trap attenuation values obtained at f_{ap} and f_{as} in Figs. 14 and 15 are large. Fig. 16 shows the test result in the VIF circuit of TV and VCR for the PAL system shown in Fig. 13(b). The solid and broken lines show the characteristics without and with this new additional trap resonator, respectively. Comparing the two lines, the trap attenuations are improved by 15 dB at f_{ap} and by 16 dB at f_{as} simultaneously in one resonator without change in the attenuation at f_c and f_p. The trap attenuations obtained at f_{ap} and f_{as} are enough large for practical use in the VIF circuit.

V. Conclusion

We have developed a new BGS wave resonator with three resonances by using responses excited by a weighted IDT and generated due to the $2N \pm 2$th mode reflection responses at free edges of substrate. For the European PAL system the trap attenuations were improved by 18 dB at f_{ap} and by 21 dB at f_{as}, and for the US NTSC system they were improve by 19 dB at f_{ap} and by 24 dB at f_{as} in the simple test circuit. In applying in the VIF test circuit of the PAL system, this new resonator was able to improve the trap attenuations of 15 dB at f_{ap} and 16 dB at f_{as} simultaneously in one resonator. It is confirmed that this resonator provides the sufficient attenuation for practical use both at f_{ap} and f_{as} in the VIF circuits of TV and VCR in one resonator.

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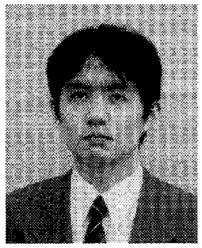

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