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Ultra-wideband ladder filters for digital TV band
DTV バンド用超広帯域ラダーフィルタ

Michio Kadota[1] and Shuji Tanaka[1] ([1]Tohoku University)
門田 道雄 [1], 田中 秀治 [1] ([1] 東北大学大学院)

1. Introduction

Cognitive radio is researched to use vacant digital TV (DTV) channels (called white space) in a frequency range from 470 MHz to 710 MHz in Japan and USA, which is composed of 40 channels with 6 MHz bandwidth (BW) each.[1,2] Cognitive radio uses a single white space channel, two consecutive white space channels or four consecutive white space channels, which offers WiFi communication with a BW of 5, 11, or 23 MHz, respectively. Therefore, cognitive radio requires tunable filters with wide tunable frequency range from 470 to 710 MHz and tunable BW of 5, 11, or 23 MHz.[1-5)] For this application, authors reported a tunable filter using 0th shear horizontal (SH_0) mode of plate wave resonator in a (0º, 120º, 0º) $LiNbO_3$ with wide BW.[6)] However, its tunable range was 13% and was not enough to cover full DTV band. On the other hand, two other systems to contribute the cognitive radio systems were reported. One is an up-conversion type RF front-end including BW-tunable filters as shown in Fig. 1.[2-4)] The other is a system combining a wideband filter fully covering the DTV and tunable band rejection filters shown in Fig. 2.[5)] Both systems strongly require a passband filter with an ultra-wide BW fully covering the DTV band and steep shape factor (20 dB BW/6 dB BW : ideal value is 1).

An SH_0 mode plate wave in a thin (0º, 117.5-120º, 0º) $LiNbO_3$ thin plate has a larger electro-mechanical coupling factor k^2 than 50%.[6)] This time, authors fabricated ultra-wideband T-type ladder filters composed of 3 resonators using the SH_0 mode plate wave resonators. Their ladder filters have ultra-wide BWs from 41% to 51%, which fully cover Japan and USA DTV bands, and EU DTV band, respectively, changing wavelength ratio (WR =λ_p/λ_s) of parallel and series resonators.[7)] Besides, the authors fabricated π-type ladder filters with apodized interdigital transducers (IDTs) to remove many periodic small ripples due to transverse mode observed in their frequency characteristics.

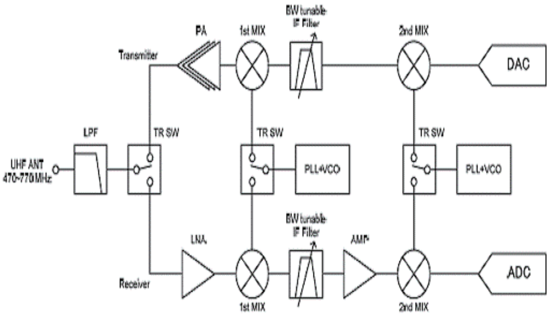

Fig. 1 Block diagram of up-conversion-type RF Front-end for IEEE802.11af using bandwidth tunable filters.

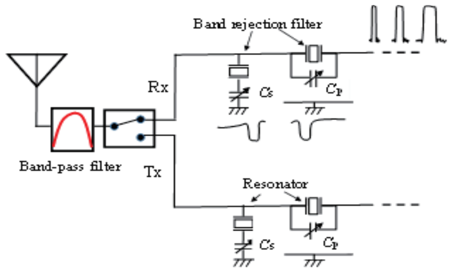

Fig. 2 Block diagram for cognitive radio system using ultra-wide band-pass filter covering fully DTV band and band rejection filters.

2. Ladder filters without apodizing IDTs

The authors reported that SH_0 plate wave in a (0º, 117.5-120º, 0º) $LiNbO_3$ thin plate (thickness < 0.1λ) has a larger coupling factor than 50%.[6)] The authors fabricated T-type ladder filters composed of 3 SH_0 mode plate wave resonators in (0º, 120º, 0º) $LiNbO_3$ thin plate (610nm thickness). Fig. 3 shows a T-ladder filter device and the filter frequency characteristic with WR of 1.39. Many periodic small ripples due to transverse mode have been observed in their pass band because apodized IDTs were not used. Fig. 4 shows 6 dB BWs as a function of WRs by white circles. Their BWs are relative to the WRs. Table I shows their filter design parameters.

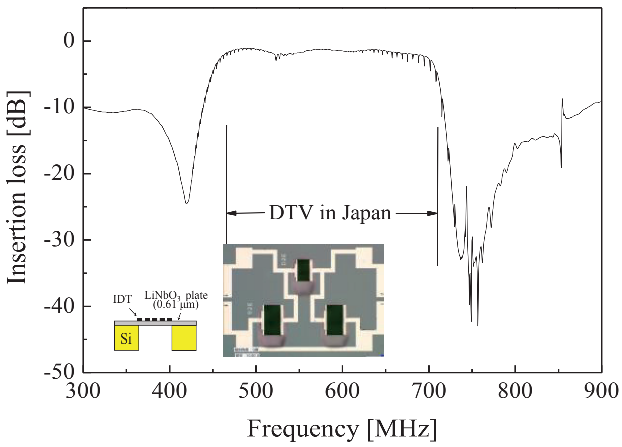

Fig. 3 T-type ladder filter device and the frequency characteristic with WR of 1.39.

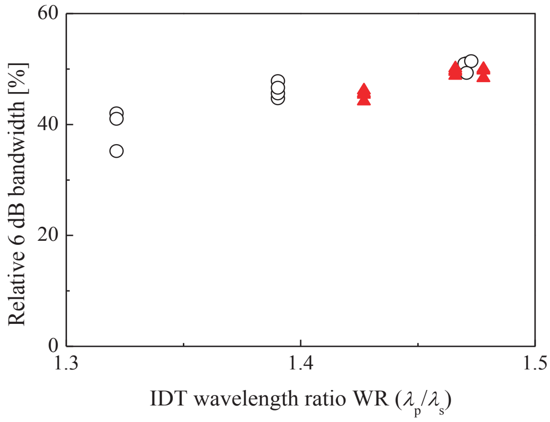

Fig. 4 6 dB BWs of ladder filters as a function of WRs. The white circles and the red triangles represent BWs of T-type (AR=0%) and π-type (AR=60%) ladder filters, respectively.

Table I Design specifications of ladder filters.

	T-type ladder filter		π-type ladder filter	
	parallel arm	series arm	parallel arm	series arm
Center frequency (MHz)	590		590	
Plate thickness (μm)	0.61		0.56	
Normalized thickness	0.078 to 0.073λ	0.108 to 0.103λ	0.068 to 0.71λ	0.101λ
Al IDT thickness (μm)	0.21		0.2	
Normalized thickness	0.027 to 0.025λ	0.037 to 0.036λ	0.025 to 0.026λ	0.036λ
λ of IDT (μm)	7.81, 8.05, 8.31	5.65, 5.79, 5.91	7.81, 8.05, 8.13	5.48, 5.50, 5.51
IDT pairs	60		60	
Apodized ratio of IDT	0%		60%	
Aperture (λ)	40 to 60		56 to 84	
MR of IDT	0.35	0.39	0.3(design)	0.3(design)
Grating reflector	30, 35, 40 fingers each		30, 35, 40 fingers each	
WR(λp/λs)	1.32, 1.39, 1.47		1.43, 1.47, 1.48	

3. Ladder filters with apodized IDTs

The transverse mode ripples are improved by using apodiz IDTs.[8)] Therefore, π-type ladder filters composed of 3 resonators with IDTs of apodizing ratio (AR) 60% were fabricated. Maximum apertures of IDTs with AR 60% were designed to 1.4 times of that of non apodized IDTs so that impedances of resonators without and with apodized IDTs might be same. The used substrate is (0º, 115º, 0º) $LiNbO_3$ thin plate (thickness 555 nm). Table I shows their design parameters. Fig. 5 shows a ladder filter device and the frequency characteristic with WR of 1.43. Ultra-wide BW (6 dB BW of 46%) is obtained. Red triangles in Fig.4 show their 6 dB BWs. The tendency is similar with that of the T-type ladder filters. Their BWs at WR of 1.43 and 1.47 fully cover the DTV band in Japan and USA, and that at WR 1.48 in EU. Therefore, the ultra-wideband ladder filters are useful for above-mentioned cognitive systems in Figs. 1 and 2. In addition to them, they are useful for the cognitive system combined a wideband filter and 3 kinds of IF filters with BW of 5, 11, and 23 MHz.

Although a lot of periodic small ripple due to transverse mode disappeared by using apodized IDT, some large ripples are observed. The large ripples are not observed in Fig. 3. The large ripples are due to the above-mentioned wider aperture designed to have same impedance as the T-ladder filter. It is considered that the large ripples in Fig. 5 might be improved by narrowing the IDT aperture.

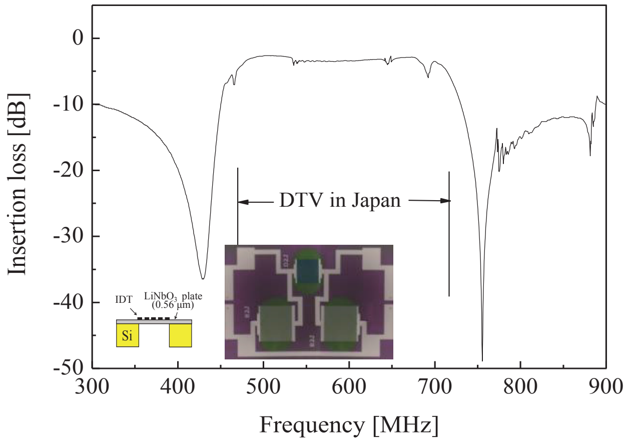

Fig. 5 π-type ladder filter device and the frequency characteristic with WR of 1.43.

4. Conclusion

T-type ladder filters with non apodized IDTs and π-type ones with AR of 60% were fabricated. BWs of both filters can be controlled by changing the WRs. They can fully cover the DTV band in Japan, USA, and EU by changing WR. Therefore, the ultra-wideband ladder filter are useful for the proposed cognitive radio systems.

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