Study of SAW Chirp- Z Transform for an Enhancement of OFDM/OFDMA Systems

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Abstract The surface acoustic wave has a definite advantage in the Fourier transform for distribute of OFDM that is converted into the OFDM signal and received in power consumption and has a super-high-speed operation. The operation speed of the SAW Chirp-Z transform processor composed of SAW Down Chirp Filter of bandwidth 100MHz and N=2,048 becomes 5.5GFLOPS. The condition that the temperature coefficient of the delay time of SAW Down Chirp Filter becomes zero was shown, and the OFDM system for 5GHz band high-speed wireless LAN that used optimization SAW Chirp-Z transform that had the positive reverse-Fourier transform function as an application example was examined. The SAW Chirp-Z transform is the only method by which a long-lived handset can be achieved.

Keyword Orthogonal Frequency Division Multiplexing, 802.11n High-Speed Wireless, 5.5GFLOPS, SAW Chirp-Z transform, SAW Down Chirp Filter

1. Introduction

Table 1 shows historical details of OFDM. Four aspect phase modulation systems that was able to be multiplexed was introduced as a military shortwave wireless at telephone call road intervals when it was suitable not to use channel filter for the transmission from a Collins wireless company in 1957's OFDM has been researched as a multi-channel data transmission in Bell Laboratory in 1966 afterwards. It was the about same and fast Fourier transform (FFT) algorithm that is enhancing the algorithm of Yates known by statistics well advocated by the Lincoln laboratory. It came to be able to achieve FFT in a hard target by VLSI technology, and OFDM saw real development in the 1990's.[１]

The signal processing system that had used the Chirp-Z transform in the 1980's was examined domestically.[2], [3] Surface acoustic wave has a definite advantage in the Fourier transform for distribute of OFDM that is converted into the OFDM signal and received in power consumption and has a super-high-speed operation n processing performance. The operation speed of the SAW Chirp-Z transform processor composed of SAW Down Chirp Filter of bandwidth 100MHz and N=2,048 becomes processor composed of SAW Down Chirp Filter of bandwidth 100MHz and N=2,048 becomes 5.5GFLOPS. The condition that the temperature coefficient of the delay time of SAW Down Chirp Filter becomes zero is shown, 802.11n high-speed, wireless LAN in Japan that shows in Figure 1 as an application example allocates the band of 20MHz in 5GHz band, and 4 pieces and each 5 bands of 11 pieces and 40MHz is allocated newly with 8 pieces. In this report, the OFDM system for 5GHz band high-speed, wireless LAN that uses optimization SAW Chirp transform that has the positive reverse-Fourier transform function is described. The condition that the temperature coefficient of the delay time of SAW Down Chirp Filter becomes zero is shown, 802.11n high-speed, wireless LAN in Japan that shows in Figure 1 as an application example allocates the band of 20MHz in 5GHz band, and 4 pieces and each 5 bands of 11 pieces and 40MHz is allocated newly with 8 pieces. [4] In this paper, the OFDM system for 5GHz band high-speed, wireless LAN that uses optimization SAW Chirp transform that has the positive reverse-Fourier transform function is described.

1957	It uses it first by military shortwave wireless (military HF radio). R.R.Moisir,″ A data transmission system using pulse phase modulation″ IRE Conv. Rec. 1st Nat'l Conv Military Electronics(Washington, D.C., June. 17-19,1957) pp.233-238.
1965	J.W.Cooley & J.W.Tukey,″ An algolithm for the machine calculation of complex Fourier serries″, Mathematics of Computation, 19, 90, pp.297-301
1966	It reports on the multichannel data transmission in Bell Laboratory with the band limiting R.W.Chang,″ Synthesis of band-limited orthogonal signals for multi-channel data transmission″, Bell Syst.Tec. J., vol. 45, pp.1775-1796, Dec. 1966
1971	Freeny et al., ″ System Analyis of a TDM-FDM translator digital A-type Channel Bank,″ IEEE Trans.COM-19、No.6, pp.1050-1059, Dec.1971
1975	R.Maruta et al., ″On Prossing Algorithms for the TDM-FDM Transmultiplexer.″ IEICE Technical Repors, CS75-190, pp.89-96, 1975
1990-	Digital audio in Europe, broadcasting video, and digital local loops
1999-	IEEE 802.11a wireless LAN
2003-	IEEE 802.11n multiband OFDM: Ultra wideband wireless

Table 1. Historical details of OFDM

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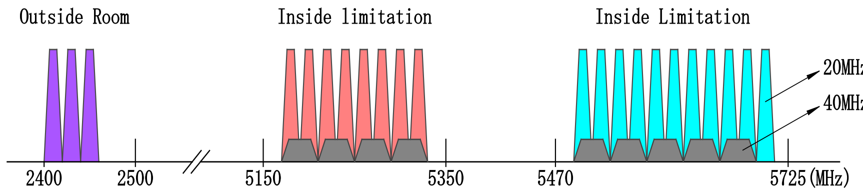

Figure 1. Wireless LAN frequency arrangement

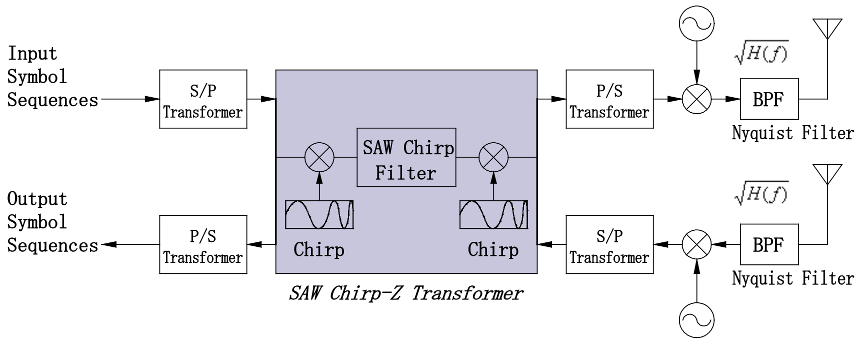

Figure 2. OFDM system that used SAW Chirp-Z transform

2. Application of SAW Chirp-Z transform to OFDM

Figure 2 is OFDM system that used the SAW Chirp-Z transform. The feature of this system does the SAW Chirp-Z transform circuit and fast Fourier transform (IFFT) and FFT are done by using together sending and receiving. Nyquist Filter has been installed in the sending and receiving antenna. The high-speed data is divided into the parallel signal of N piece and the OFDM signal is transmitted with low speed modulation FDM (Frequency Division Multiplex) channel. The influence of the delay decentralization caused by dividing the transmission line into a lot of narrowband channels on the multiple propagation paths can be decreased. Concretely, division into the FDM channel processes the signal by FFT by IFFT by the SAW Chirp-Z transform on the receiving side at the transmitting end. This system solves the problem though the amount of the operation is a huge thing in one difficult point of the digital signal processing of the past. 802.11n high-speed, wireless LAN in Japan allocates the band of 20MHz in 5GHz band and 4 pieces and each 5 bands of 11 pieces and 40MHz is allocated newly with 8 pieces. The communication network for 5GHz band high-speed, wireless LAN in Table 2 is examined here.

RF bandwidth	5.15～5.35(GHz)
Allocation bandwidth	200(MHz)
Use wireless bandwidth	20(MHz)
Duration T of transmission sign	20(μs)
Number N of FDM channels	400

Table 2. 5GHz band high-speed, wireless LAN specification

The maximum of bandwidth B is from 150μs to 200μs it and BT=10^4 in about 1GHz in BT product of the SAW processor at the continuance time.

The circuit of Figure 3(a) is shown with dual form like the circuit of Figure 3(b). In a current digital method, FFT uses FFT in 2,048 points. The speed of the transmission sign is times of $1/T = 50{,}000$ cycle/second. The operation speed necessary for FFT at this time becomes

$$N \cdot \log(N)/T = 2{,}048 \times 11 \times 50{,}000 = 1.1264(\text{GFLOPS})$$

.

This multiplication is multiplication by the complex number. The number of real multiplication is the four times, and it becomes 4.5056GFLOPS amount of the operation and achievement is difficult in the portable terminal. The amount of a necessary operation can be decreased sharply by using the SAW Chirp-Z transform processor as the solution. The amount of a necessary operation can be decreased sharply by using the SAW Chirp-Z transform processor as the solution. There is a feature that the SAW processor does not need power consumption with an analog device, be able to more batch form the SAW device pattern on a piezoelectric wafer by the photolithography technology just like LSI, and the cost can be supplied dramatically and more low-cost than LSI. $Bi_{12}GeO_{20}$ RAC type SAW Chirp Filter does not depend from the specification on the frequency band that selects it, and the physical size of chip width is several mm, and if it is 18mm, the size of the long direction is enough.

3. Digital processing by SAW processor

In the BT product of the SAW processor, the continuance time is 150μs - 200μs, the maximum of bandwidth B is $BT_{max} = 10^4$ in about 1GHz. The circuit of Figure 3(a) is shown with the circuit of dual form like the circuit of Figure 3(b). The input signal must have bandwidth B_s and continuance time T_s. As for the signal, if this is sent to Chirp Filter (bandwidth $B_f = B_s + B_p$ and delay time T_f), this T_c is shown to the spectrum analysis time in Figure 3(c) for the input chip that comes one after another because it appears in the output of Filter by finishing passing in time. Because the FFT algorithm can be used at digital processing, and the complex number butterfly circuit process times of $(N/2)\log_2 N$ (It is assumed that ten is basic operated by the butterfly of one time), the floating point arithmetic becomes an operation of times $5N\log_2 N$. If this is matched to $N = B_s T_s$, the sound equivalence operation speed becomes $5B_s\log_2(B_s T_s)$.

Figure 4 shows the computational speed of the SAW processor by the parameter of bandwidth and N. The operation speed of $B_s = 100\text{MHz}$ and N =2,048 becomes 5.5GFLOPS.

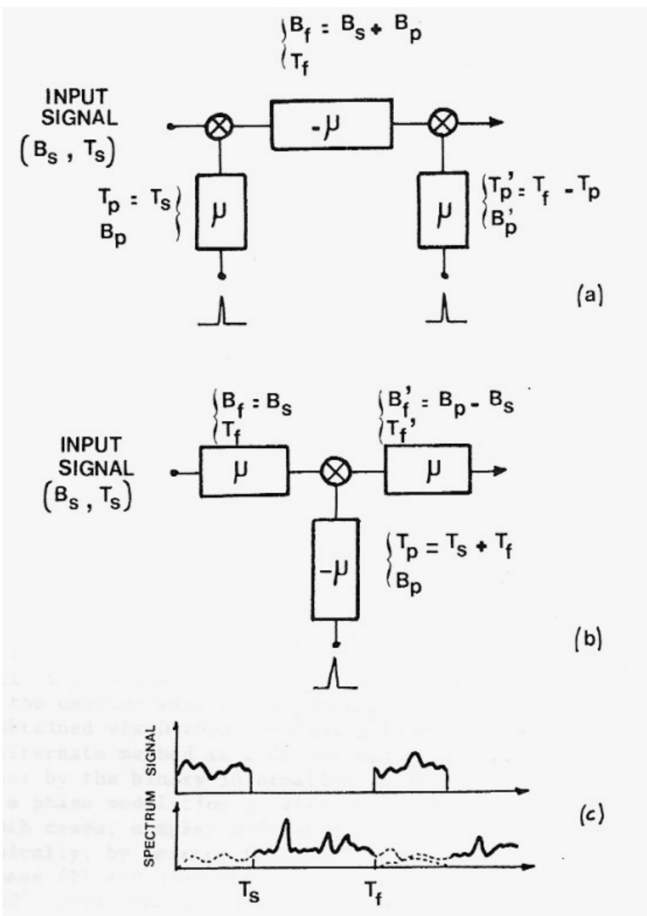

Figure 3. Digital processing by SAW processor

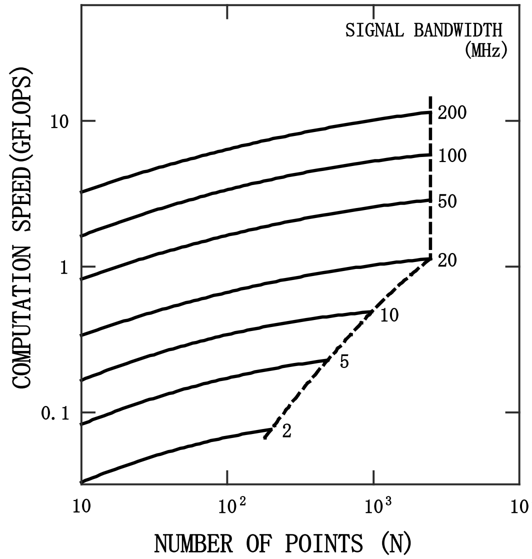

Figure 4. Calculation speed of SAW Chirp-Z transform

4. Temperature characteristic of delay time of SAW Chirp Filter

The temperature property of RAC type SAW Chirp filter is examined.

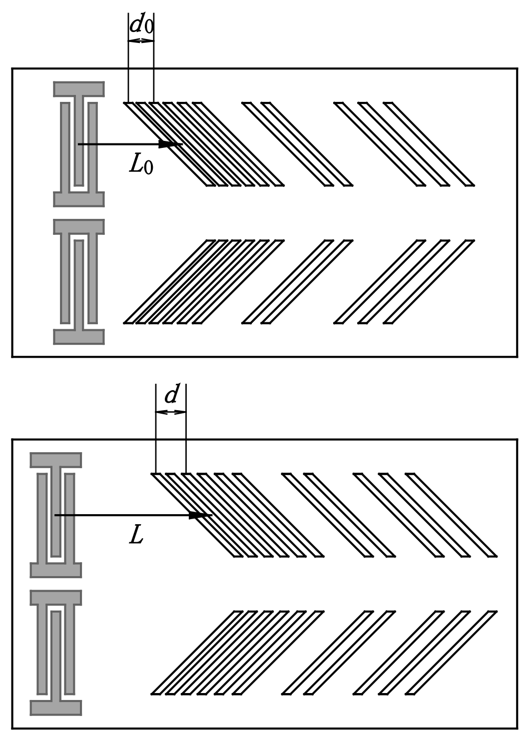

Figure 5. Structure of RAC type SAW Down Chirp Filter

The temperature is indicated T_0 and the frequency f_0 and delay time of τ_0 are indicated as follows.

$$f_0 = \frac{v_0}{d_0} \quad (1)$$

$$\tau_0 = \frac{L_0}{v_0} \quad (2)$$

Here, d_0 and L_0 are the electrode finger cycles and the spread distances.
In general, the frequency f at an arbitrary temperature is shown by the next expression, considering the temperature coefficients up to the third.

$$f = \frac{v}{d} = f_0\left\{1 - \sum_{n-1}^{3}(Tl^{(n)} - Tv^{(n)})\Delta T^n\right\} = f_0\left\{1 - \sum_{n-1}^{3} TC^{(n)}\Delta T^n\right\} \quad (3)$$

However, it is $TC^{(n)} = Tl^{(n)} - Tv^{(n)}$. Here, $Tl^{(n)}$ and $Tv^{(n)}$ n are the following linear coefficient of expansions, and coefficients of the SAW speed temperature. Similarly, delay time τ at an arbitrary temperature is shown as follows.

$$\tau = \frac{L}{v} = \tau_0\left\{1 + \sum_{n-1}^{3}(Tl^{(n)} - Tv^{(n)})\Delta T^n\right\} = \tau_0\left\{1 - \sum_{n-1}^{3} TC^{(n)}\Delta T^n\right\} \quad (4)$$

The frequency decentralization characteristic of the decentralized delay line is put as follows at reference temperature T_0.

$$\tau_0 = G(f_0)$$

The distributed property at the arbitrary temperature is as follows from expression (3) and (4).

$$\tau \cdot (1 - \sum_{n-1}^{3} TC^{(n)}\Delta T^n) = G(f(1 + \sum_{n-1}^{3} TC^{(n)}\Delta T^n))$$

$$\tau \approx (1 + \sum_{n-1}^{3} TC^{(n)}\Delta T^n)G(f(1 + \sum_{n-1}^{3} TC^{(n)}\Delta T^n))$$

$$\approx (1 + \sum_{n-1}^{3} TC^{(n)}\Delta T^n)\left[G(f) + fG'(f)\sum_{n=1}^{3} TC^{(n)}\Delta T^n\right]$$

therefore,

$$\tau \approx G(f) + \left[G(f) + fG'(f)\right]\sum_{n=1}^{3} TC^{(n)}\Delta T^n \quad (5)$$

It is shown like this. Therefore, the temperature coefficient of delay time in the reference temperature T_0 can be requested as follows.

However, it is $C_T = TC^{(1)} = Tl^{(1)} - Tv^{(1)}$.

$$\frac{1}{\tau}\frac{\partial \tau}{\partial T} = \frac{G(f) + fG'(f)}{G(f)} C_T \quad (6)$$

In addition, it obtains from expression (3) as follows.

$$\frac{1}{f}\frac{\partial f}{\partial T} = -C_T \quad (7)$$

Temperature coefficient C_T and distributed property $G(f)$ of the substrate take part in the temperature coefficient of delay time. As for the distributed property of linear down chirp filter, delay time decreases monotonously as the frequency increases. The case where the $T_0 + \Delta T$ temperature changes from Figure 6 into reference temperature T_0 like clearness is shown in the short dashed line.

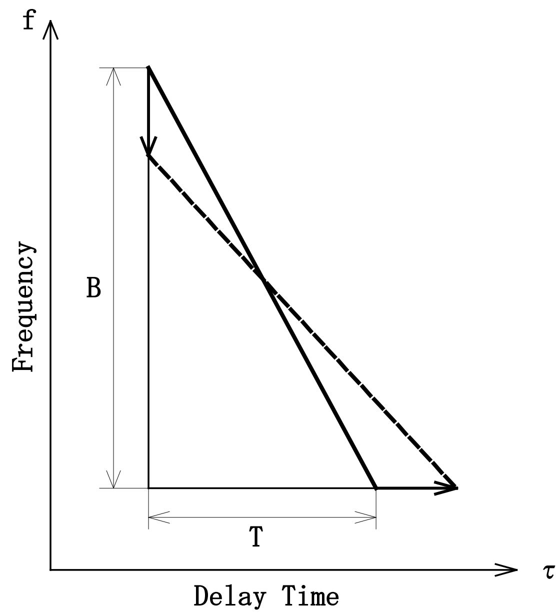

Figure 6. F-τ temperature property of SAW Down Chirp Filter

It approximates by the linear expression in reference temperature T_0 at delay time τ_0.

$$\tau_0 = af_0 + b \quad (8)$$

The delay time τ is shown from the expression (5) by the next expression at arbitrary temperature T.

$$\tau = af + b + (2af + b)\sum_{n=1}^{3} TC^{(n)}\Delta T^n \quad (9)$$

In addition, the temperature coefficient of the frequency is shown by expression (6) and (7) at delay time.

$$\frac{1}{\tau}\frac{\partial \tau}{\partial T} = \frac{2af+b}{af+b}C_T \qquad (10)$$

$$\frac{1}{f}\frac{\partial f}{\partial T} = -C_T \qquad (11)$$

When expression (10) is transformed, it becomes (12).

$$\frac{1}{\tau}\frac{\partial \tau}{\partial T} = \frac{2f/f_0-1}{f/f_0-1}C_T \qquad (12)$$

Figure 7 is a relation of the expression (12). The molecule is in f, and the temperature coefficient of almost zero and zero, in a word, delay time is and there are zero and a frequency that vanishes almost. By the way, the electrode is usually used as for the temperature coefficient of the metal film that composes the substrate and the reflecting grating. As for the speed of the surface wave of $Bi_{12}GeO_{20}$, the length of the substrate of SAW Chirp Filter becomes below the half of $LiNbO_3$, and becomes upper big advantage to design the device below the half of $LiNbO_3$. The temperature characteristic of the delay time of this $Bi_{12}GeO_{20}$ substrate is a monotone increasing. The temperature characteristic of the electrode delay time is a monotone decreasing on the other hand, and the temperature inclination at delay time is brought close by the film thickness and the value the electrode is used for the reflecting grating by finishing changeability can be unlimitedly brought close to zero.

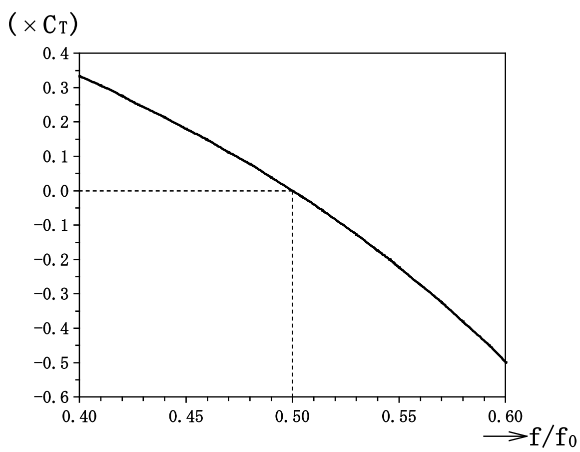

Figure 7. Temperature property of SAW Chirp-Z transform processor

5. Principle of Chirp-Z transform

Figure 8 explains the principle of the Chirp-Z transform. Because the characteristic of the delay time of the chirp signal becomes A in figure when the Chirp signal of frequency f_a is impressed directly to Down Chirp SAW decentralized delay line for the convolution, the position of the compression pulse becomes P point on the axis of time. It is an output signal that this corresponds to frequency f_a. The becoming it input signal is mixed, and next, center frequency f_0 of the chirp signal shifts $f_a + f_s$ and $f_a - f_s$, and the characteristic of the delay time of the Chirp signal for that changes into frequency f_s with B and C in figure, too, when impressing it to Down Chirp SAW decentralized delay line for the convolution the change in a similar chirp signal. Time that the compression pulse appears becomes $f_a + f_s$ Q $f_a - f_s$ R. The distance of this compression pulse becomes possible for spectrum to observe with the time axis on the axis of time because it is equivalent to f_S of the input signal it. When $f_a = f_0/2$ is impressed to Down Chirp SAW decentralized delay line of center frequency f_0 as Chirp signal, spectrum obtains it on the axis of the time of input signal f_s.

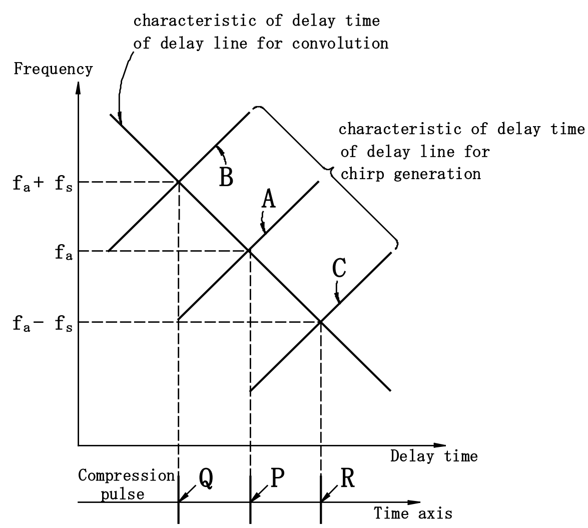

Figure 8. Principle of Chirp-Z transform

6. Summary

The OFDM technology is applied widely to not only VDSL but also ADSL of the cable system, ground wave digital, Television Broadcasting, wireless LAN, and the mobile communication, etc. , and is becoming the core technologies of the next generation broadband wireless telecommunications methods such as WiMAX and LTE. It had a definite advantage in transform into the OFDM signal and the Fourier transform for amount of wave in power consumption and SAW Chirp-Z transform OFDM system that had a super-high-speed operation processing performance was examined. It has been understood to be able to show the condition that the temperature coefficient of the delay time of SAW Down Chirp Filter becomes zero, and to achieve the OFDM system for 5GHz band high-speed, wireless LAN that uses optimization SAW Chirp-Z transform that has the positive reverse-Fourier transform function as an application example with the SAW Chirp-Z transform processor with a definite advantage in power consumption.

Reference

[1]. For instance,

a) P.A.Bello, "Selective fading limitations of the Kathryn modem and some system design considerations, " IEEE Trans. Communi. Tech. vol.COM-13, pp.320-333, April 1965

b) B. Hirosaki, " An orthogonally multiplexed QAM system using the discrete Fourier transform, " IEEE Trans. Communi. Tech. vol.COM-29, pp.982-989, July 1981

c) L.J. Cimini,Jr. "Aanalysis and simulation of a digital mobile radio channel using orthonal frequency division multiplexing, " IEEE Trans. Communi. Tech. vol.COM-33, no.7, pp.566-675, July 1985

d) M.Alard and R.Halbert-Lasslle, "Princples of modulation and channel coding for digital broad-casting for mobile receivers, " EBU Review, no. 244, pp.47-69, Aug. 1987.

[2]. Tohru Honda, Isao Imai and Takeshi arukawa, "Improvement of FM-CW Rader Performance with Chirp-Z Transform Signal Processing," (in Japanese)
Research Associate; Dept. of Electrical Engineering, The National Defense Academy, vol.19, No.2, pp.65-75, 1981 June. (in Japanese)

[3]. Takeharu Kohri, Masahiro Morikura, Shuzo Kato, " Non-regenerative Onboard FDM/TDM Transmuliplexer," IEICE Technical Report, pp. 25-31, SAT85-24,1984 (in Japanese)

[4]. Hiroshi Hojo, NTT technical journal, pp.53-57, 2008.3 (in Japanese)

[5]. H. Gautier, "Digital Processors Using SAW Devices," 1981 IEEE Ultrasonics Symposium, pp.206-219

[6]. Kimio Shibayama," Recent Trend in Signal Processing Using SAW Devices," The Journal of the Institute of Television Engineers of Japan,vol.36,No.6, pp.498-505,1982 (in Japanese)

[7]. Yasutaka Shimizu, Taku Nakata, " Temperature Dependence of SAW Dispersive Delay Line," IEICE Technical Report, pp. 31-38, US79-26 (in Japanese)

[8]. Toshihiko Kitano, Katsuhiko Nishikawa," High Resolution Chirp Z-Transform using 110μs SAW Dispersive Delay Line," IEICE Technical Report, pp. 7-12, SAT85-24 (in Japanese)

[9]. Takaya Watanabe, Osamu Ichiyoshi, " Technical advancement of SAW Chirp & Convolver in mobile communication systems, IEICE Technical Report, pp. 39-44, US2008-57 (in Japanese)