Single Layer Type SAW FM discriminator

°
Y. H. Choi, Y. J. Chung, and Y. S. Park, and K. C. Whang

Department of Electrical Engineering, Yonsei University, Seoul, Korea

Abstract

In this work we describe a new type of SAW FM discriminator which is structurely single layer planar type and uses the elastic nonlineatity compared with acoustoelectric SAW FM discriminator.
This device shows successful FM discrimination of analog as well as digital signals.

1. Introduction

A study of acoustoelectric FM demodulator which uses a space charge nonlinearity induced by SAW in an adjacent silicon is reported.
But this device has the problem of maintaining the uniform airgap.
In this paper a new type of SAW FM discriminator which is structurely single layer planar type and uses the elastic nonlinearity is proposed.
This device consists of the two IDTs, horn type beanwidth compressor and output pad on the surface of YZ-$LiNbO_3$. In this device the two IDTs are arrayed to excite the collinear surface acoustic waves, the horn type beamwidth compressor is used to enhance the elastic nonlinearity and the output pad is designed to detect the normal component of the surface acoustic waves.
This device has shown the successful analog FM discrimination and to be applicable to the DPSK demodulation.

2. The operation principle of the planar SAW FM discriminator

A FM signal is applied to the IDT1 and IDT2 which are separated by the time delay t_0 in fig. 2-1.
The applied FM signal will excite the two collinear waves which are propagating in the same direction.
When the two collinear waves propagate through the horn type beamwidth compressor, the elastic nonlinearity is to be enhanced by compression ratio, and many higher order signals are generated due to the nonlinear interaction.
However, after spatially integrating along the length of output pad L, only the term which performs the FM demodulation, can detect the normal component of the SAW across the output pad.

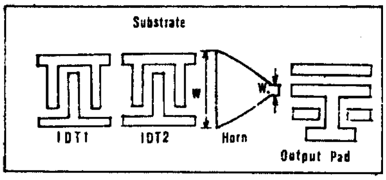


Fig.2-1. The configuration of planar SAW FM discriminator.

If the single tone FM signal

$$f(t) = A\cos(\omega_c t + \beta\sin\omega_m t) \qquad (1)$$

is applied to the two IDTs, the sum of the input signal and its delay squared

$$[\,f(t) + f(f-t_0)\,]^2 \qquad (2)$$

will give rise to several second order nonlinear mixing terms because of the elastic nonlinearity. It can be shown that the only term which is of interest is

$$\begin{aligned}2f(t)f(t-t_0) &= 2AB\cos(\omega_c t + \beta\sin\omega_m t)\cos[\omega_c(t-t_0) + \beta\sin\omega_m(t-t_0)]\\ &= AB\cos[\omega_c t_0 + (2\beta\sin(\omega_m t_0/2)) + AB\cos[2\omega_c t - \omega_c t_0 + (2\beta\cos(\omega_m t_0/2))\sin(\omega_m t - \omega_m t_0/2)]\end{aligned} \qquad (3)$$

where A and B are associated with amplitude of f(t) and $f(t-t_0)$ respectively, $\beta = \Delta\omega/\omega_m$, is the modulation index, $\Delta\omega$ is the peak frequency deviation, ω_m is the modulating frequency and ω_c is the carrier frequency.

The open circuit voltage across the output pad is spatially integrated along the length of the output pad L and expressed as follows

$$\begin{aligned}v_{op}(t) &= \int_0^L f(t-z/v)f(t-t_0-z/v)\,dz\\ &= KAB\sum_{n=-\infty}^{\infty} J_n[2\beta\cos(\omega_m t_0/2)]\cdot\frac{\sin[(2\omega_c+n\omega_m)L/2v]}{(2\omega_c+n\omega_m)L/2v}\cdot\cos[2\omega_c t-\omega_c t_0+n(\omega_m t-\omega_m t_0/2)-\omega_c L/v\\ &\quad -n\omega_m L/2v)] + KAB\sum_{p=-\infty}^{\infty} J_p[2\beta\sin(\omega_m t_0/2)]\,\frac{\sin(p\omega_m L/2v)}{p\omega_m L/2v}\cdot\cos[\omega_c t_0+p\pi/2+p(\omega_m t-\omega_m t_0/2\end{aligned}$$

$$-p\omega_m L/2v]$$
$$=KAB\sum J_p[\Delta\omega t_0]\cos(p\omega_m t+\omega_c t_0+\varphi) \qquad (4)$$

where $J_n[\Delta\omega t_0]$ is the Bessel function of n-th integer.

In the above eq.(4), the action of spatially filtering comes in the form of $\sin\theta/\theta$, i.e.

$$\frac{\sin(p\omega_m L/2v)}{p\omega_m L/2v} \cong 1 \qquad p \leq 2$$
$$\frac{\sin[(2\omega_c+n\omega_m)L/2v]}{(2\omega_c+n\omega_m)L/2v} \cong 0 \qquad \text{for all } n$$

Since $2\beta\sin(\omega_m t_0/2) = \Delta\omega t_0$ when $\omega_m t_0/2 \ll 1$, the time delay t_0 is set at 0.34 μsec. Because all other terms of the Bessel function are negligible provided $\Delta\omega t_0 < 1$ since $J_p[\Delta\omega t_0] \ll J_1[\Delta\omega t_0]$ for $p \gtrless 2$, eq.(4) shows that the SAW device does demodulate the received FM SIGNAL ($n=\pm 1$ terms).

3. SAW DPSK demodulator

A SAW FM discriminator can detect the received DPSK(differential phase shift keying) signal if the time delay t between the two IDTs is replaced by the bit interval T of the DPSK signal. Fig.2-2 shows the block diagram of the DPSK demodulator.

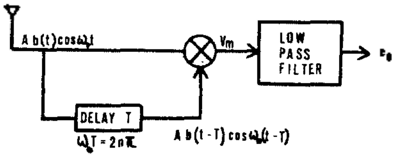


Fig.2-2. Block diagram of the DPSK demodulator.

In this figure, $b'(t)$ is the received DPSK signal. The message signal b(t) can be

$$b'(t) = b(t)\,b(t-T) \qquad (5)$$

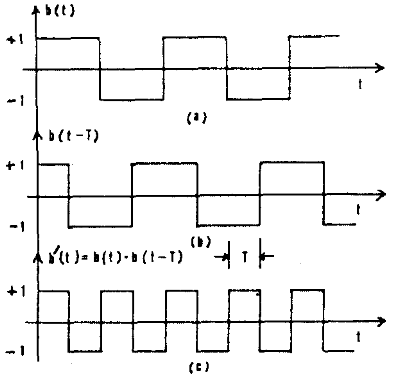


Fig.2-3. Data sequence of the received DPSK signals.

If the received DPSK signal

$$v(t) = A\cdot b(t)\cdot\cos(\omega_0 t) \qquad (6)$$

is applied to the two IDTs with time delay T, the open circuit voltage e_0 is given

$$e_0 \cong K\int^{L} b(t-z/v)\,b(t-T-z/v)\cos(\omega_0 T)dz$$
$$+ \text{higher frequency terms} \qquad (7)$$

where K is the constant

In eq.(7), the higher frequency terms are filtered out by the integration along the output pad and making the transformation of variables $u=t-z/v$, we obtain

$$e_0 \cong K\int_{t-L/v}^{t/v} b(u)\,b(u-T)du \qquad (8)$$

where $\cos\omega_0 T = 1$ for $\omega_0 T = 2n\pi$

If we make the restriction $L/v \ll T$, i.e. the length of output pad is smaller than the time delay T between the two IDTs, the integrand is a constant over the limits of integration and we ontain

$$e_0 = K'\,b(t)\,b(t-T) = K'\,b'(t) \qquad (9)$$

Eq.(9) shows that the SAW device theoretically successfully demoduate the received DPSK signal.

4. Experiment and results

The planar SAW FM discriminator consists of the two wideband IDTs at center frequency 100MHz parabolic horn type beamwidth compressor with compression ratio 11:1 and the output pad with 5 μsec pulse length which detects the normal component of the SAW.

The time delay between the two IDTs is set at 0.34 μsec and the horn type beamwidth compressor is designed by eq.(10) proposed by I.Yao.

$$\frac{dW}{dL} = \frac{2\alpha\kappa_0}{\eta_s^2\,\beta_0}$$

where W is the width of horn, L is the length of horn, α is the proportionality factor, typically less than or equal to 1, η_s is the anisotropy factor of SAW propagating on YZ-$LiNbO_3$ with shorted surface, β_0 is the propagation constant of the fundamental mode, $\kappa_0 = \eta_s(K_t^2 - \beta_0)^{1/2}$, is the transverse wave number of the fundamental mode, and K_t is the wave number of the planar SAW on YZ-$LiNbO_3$ with shorted surface.

Fig.3-1. shows the theoretical design curve of the horn.

This device is fabricated on YZ-$LiNbO_3$ by the photolithographic method.

Fig.3-2. describes the frequency response of the SAW delay line. Fig.3-3. gives the comparison between the shapes of the input modulating signals $g(\tau)$ and that of device's output demodulated signals. The FM demodulation is successfully achieved for the case of the rectangular, saw tooth and sinusoidal waves modulation. The modulating frequency is 3.5 KHz.

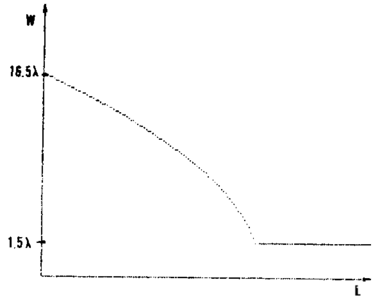
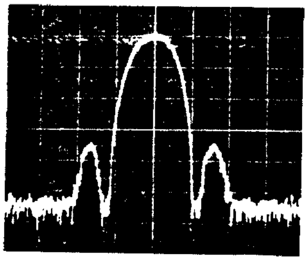
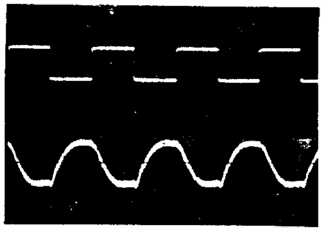


Fig.3-1. Theoretical design curve of the horn.

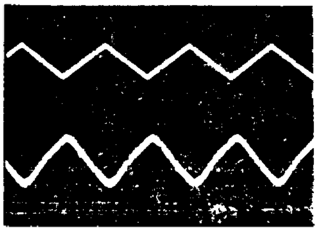


Ver.;10dB/div.
Hor.;20MHz/div.
Center frequency
; 100MHz

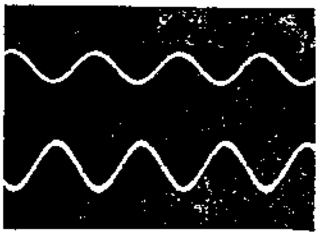
Fig.3-2. Frequency response of SAW delay line.



(a) rectangular wave



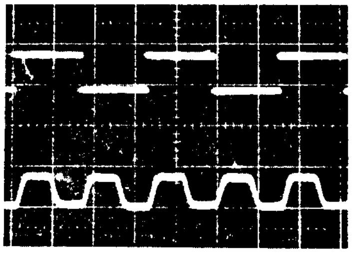
(b) saw tooth wave



(c) sinusoidal wave
upper trace;modulating signals 0.5v/div.
lower trace;demodulated signals 0.1v/div.
Hor. ; 0.1 msec./div.

Fig.3-3 Demodulated output of FM signals

This device also can be utilized for the DPSK demodulator in digital communication when the time delay between the two IDTs is set at 4 μsec and the length of the output pad is designed to detect 0.5 μsec length signal.
(Fig.3-4) describes the input modulating binary sequence $b'(t)$ [fig.2-3 (c)].



upper trace : input binary sequence Ver. 1 V/div.
lower trace ; demodulated output binary sequence Ver. 0.1 V/div.
Hor. ; 5 μsec./div.
Fig.3-4. Demodulated output of DPSK signal.

This result shows the successful demodulation of the received DPSK signal.

5. Conclusion

A new type of the planar SAW FM discriminator which consists of the two IDTs to excite the collinear surface acoustic waves, the horn type beamwidth compressor to enhance the elastic nonlinear effect and the output pad to detect the normal component of the surface acoustic waves on the surface of YZ-LiNbO$_3$, is developed.
This device has shown the successful FM discrimination and DPSK demodulation.

Reference

1. W.C.Wang,H. Schachter, F.Cassara and L.Rosenheck,"An Acoustoelectric FM Demodulator",1978 IEEE Ultrasonics Symp. Proc., p25

2. M.K.Roy, "A Rayleigh Wave Beamwidth Compressor Using Δv/v-Type Guidance",IEEE Trans. on Sonics and Ultrasonics, Vol. SU-23, No.4,July 1976, p276

3. Ph.Defranould and C.MAERFELD, "Acoustic Convolver Using Multistrip Beamwidth Compressor," 1972 IEEE Ultrasonics Symp. Proc., p224

4. R.A. Becker and D.H. Hurlbert, "Wideband LiNbO$_3$ Elastic Convolver with Parabolic Horns" ,1979 IEEE Ultrasonics Symp. Proc. , p.729

5. I.Yao, "High Performance Elastic Convolver with Parabolic Horns", 1980 IEEE Ultrasonics Symp. Proc., p.37