HYBRID FET/SAW PROGRAMMABLE TRANSVERSAL FILTER*

Carl M. Panasik

Texas Instruments Incorporated
P. O. Box 226015 MS 255
Dallas, Texas 75266

Summary

A programmable transversal filter is described which employs hybrid tap weight circuitry to produce continuously adjustable tap weight magnitude and sign. The breadboard consists of a $LiNbO_3$ surface acoustic wave device utilizing a wideband 250 MHz input IDT and a 16 tap (200 MHz) output electrode array and associated electronics. A novel sampling technique allows the output array to function from 200 to 300 MHz. Programmable tap weight changes over greater than 40 dB and at a 9 MHz rate have been demonstrated. Experimental results are compared with theoretical analyses of loss mechanisms and filter response capabilities.

Introduction

One of the most promising system design concepts to achieve cost-effectiveness in future integrated communication, navigation and identification equipments is that of programmable filters because of their versatility and wideband signal processing capabilities.[1] This paper discusses the latest advances in surface acoustic wave programmable transversal filter (PTF) technology, wherein a single unit operates as a bandpass, band-reject, adaptable, or matched filter. The number of independently programmable bandwidths and center frequencies is a function of the tap weight precision (presently 6 bit). The combination of SAW technology with integrated circuit processing makes this device an ideal, cost-effective solution for complex signal processing tasks.

Concept

The PTF concept consists of a detector array composed of quarter wavelength active electrodes interleaved with grounded electrodes, as shown in Figure 1 (grounded electrodes removed for clarity). These (200 MHz)$^{-1}$ spaced electrodes sample the electric field associated with the surface acoustic wave once each wavelength. This RF potential is then applied to the first gate of two dual-gate FETs.[2,3] These common-source configured FETs are connected individually to two drain buses. The individual tap weight control voltages are applied to gate #2.

The FETs select which drain bus (+ or -) the electrode signal is sent to and also provide for continuously variable tap weight amplitudes. Initially, both control gates are biased to -2.0 volts for a near-zero valued tap weight. A positive weight is produced when the control gate voltage of the upper FET is increased in a positive manner. Likewise, a negative weight is produced when the lower FET control gate is biased on. Operation of this circuit for tap weight magnitude below 0.1 utilizes both FETs in a differential mode.

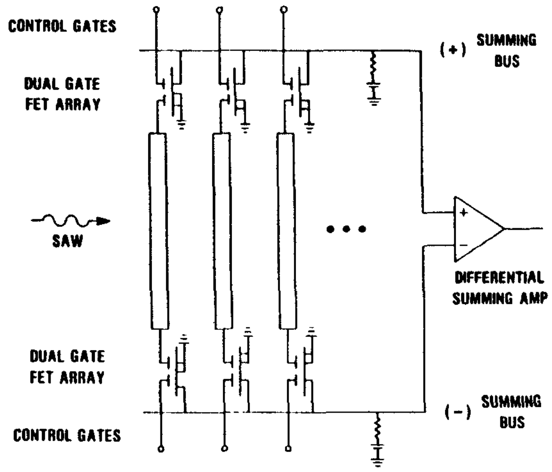


Figure 1. Programmable transversal filter concept

Tap Weight Calculation

The initial PTF objective is to translate a fixed bandwidth sinx/x function to any center frequency from 200 to 300 MHz. The translation procedure is graphically outlined in Figure 2. An infinite set of delta functions in the time domain corresponds to an infinite set of delta functions in the frequency domain spaced by the inverse of the time sample (Δt). The PTF has 16 time domain samples, therefore the time domain delta functions are time gated (Figure 2b) producing the sinx/x response in the frequency domain. Frequency translation of these sinx/x functions is accomplished by modulating the tap weights with a slowly varying cosine whose frequency corresponds to the difference between the spatial sampling frequency (f_0= 200 MHz) and the desired center frequency (f_c). Because the time domain is sampled, the tap weights are

$$h(t_n) = \cos(2\pi t_n(f_c-f_0)) \qquad (1)$$

where $t_n = n*\Delta t = n/200$ µsec. As an example, a 225 MHz center frequency has tap weights given by

$$h(t_n) = \cos(2\pi n\Delta t(225-200)) = \cos(2\pi n\cdot 25/200) = \cos(n\pi/4).$$

Therefore, the tap weights are 1., .707, 0., -.707, -1., -.707, 0., .707, 1., etc. Using this procedure, other passband responses other than sinx/x can also be translated in frequency.

* This work was supported by RADC and AFWAL under Contract F33615-80-C-1211.

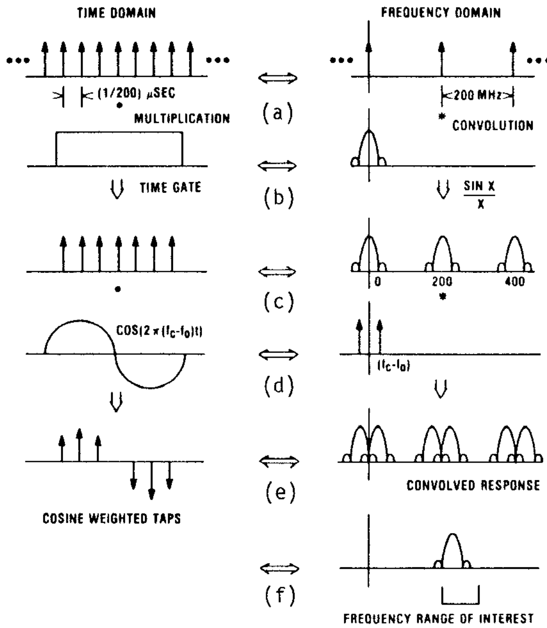


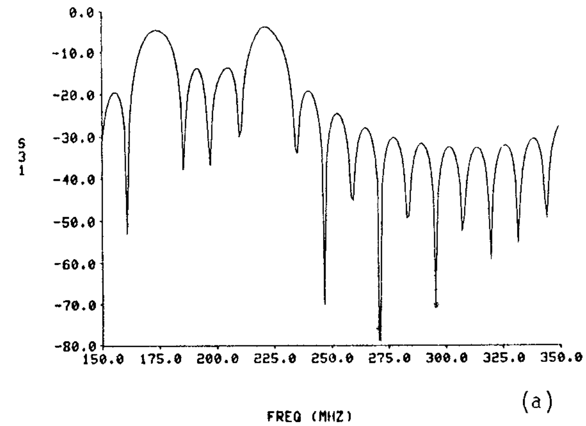
Figure 2. Programmable transversal filter frequency translation procedure
(a) an infinite set of time and frequency domain delta functions
(b) time window function
(c) gated delta functions
(d) multiplication by $\cos(2\pi(f_c-f_o)t)$
(e) cosine modulated tap weights
(f) filtered frequency domain

Theoretical Analysis

The output sampling electrodes of the PTF are connected to an almost open circuited load. This induces a regeneration effect through the individual electrodes which somewhat distorts the passband response.[4,5] A theoretical analysis of this effect has been performed using a field theory based scattering matrix approach to transducer modeling.[6] Results are presented in Figure 3 where the transmission coefficient (S_{31}) of 16 active weighted taps is plotted versus frequency for the 225 and 275 MHz frequency translations. The analysis at this time does not take take into account mechanical reflections from the electrodes.

Further analysis to isolate the sources of breadboard insertion loss was performed using SUPER COMPACT. It was theorized that the drain-source capacitance of the 16 FETs in parallel is loading the summing buses ((A) in Figure 4a). Breadboard reflection coefficient measurements revealed that shunt inductive tuning did not produce a real impedance looking into the bus, therefore a linear circuit analysis was undertaken. Measured scattering parameters of the dual-gate FETs were used in the program. Sixteen FETs were connected to a single node (A), the calculated reflection coefficient is shown in Figure 4b. A second analysis (B) included the shunt tuning (and rfc) inductor, deQ'ing resistor and dc blocking capacitor. This moves the response counter-clockwise on the Smith chart, further from the measured response.

It is thought that a parasitic inductance has caused the discrepancy between analysis and experiment. The measurement point is approximately 0.6 inch from the PTF drain bus. Since half the distance is bond



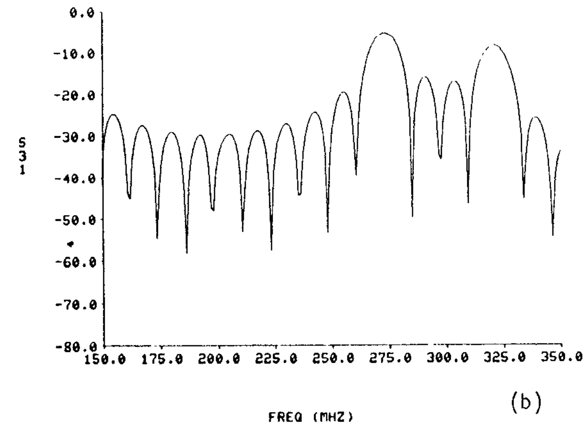


Figure 3. Theoretical transmission coefficient of 16 isolated electrodes whose voltages are weighted for two cases:
(a) 225 MHz response
(b) 275 MHz response

wire and half is package pin and component lead, the calculated inductance for 0.3 inches of bond lead inductance (12 uH) was inserted in series. The calculated reflection coefficient shown in Figure 4b (C) remains counter-clockwise from the measured coefficient. The conclusions reached are that the FET bus operates as thought and a larger than expected bond lead inductance is present.

Experiment

A hybrid programmable transversal filter has been designed and fabricated on $LiNbO_3$. The SAW device is composed of a 250 MHz wideband input transducer and an output electrode array of 16 active electrodes with adjacent grounds. The electrodes are individually bonded out to gate #1 of the dual-gate FETs (TI#MN85) The drains (output) and sources (ground) are bonded to common buses while each control gate is bonded to an external pin. The initial experiment measured a tap weight linear control range greater than 40 dB with tap switching speed (+1 to -1) on the order of 110 nsec (approx. 9 MHz).

Experimental sinx/x responses using unity valued tap weights have been produced at 200, 250 and 300 MHz.[1,2] The response at 225 MHz shown in Figure 5a is composed of the tap weights previously calculated. This compares well with the theoretical response in Figure 3a. The 275 MHz response of Figure 5b is derived from

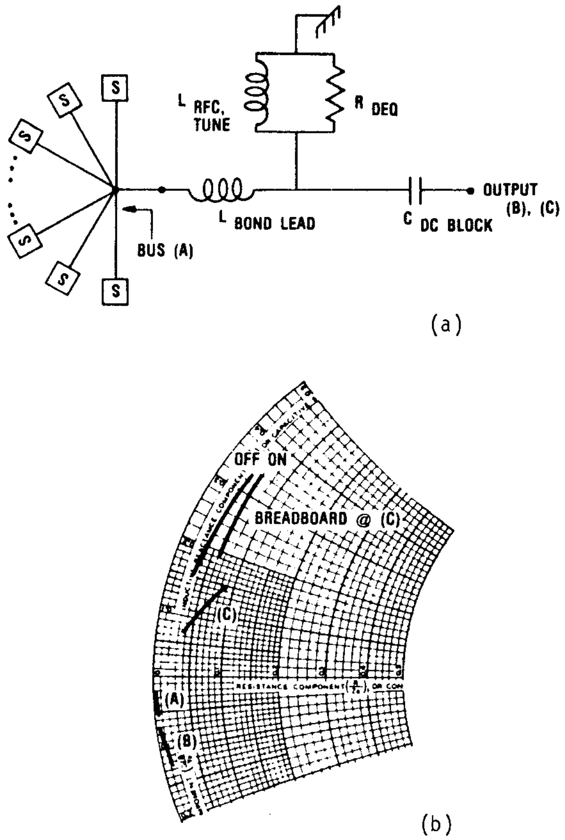


Figure 4. Linear circuit analysis
(a) schematic:
(A) FET bus
(B) output w/o bond lead inductance
(C) output w/bond lead inductance
(b) calculated reflection coefficient compared with breadboard response

$$h(t_n) = 1.,\ -.707,\ 0.,\ .707,\ -1.,\ .707,\ 0.,\ -.707,\ \text{etc.}$$

and compares well with theory in Figure 3b. These passband responses demonstrate that this programmable filter is not restricted to frequency translations dependent on unity valued tap weights, but that an arbitrary response can be translated over the entire band.

Conclusion

A programmable transversal filter has been demonstrated which shows potential for use in the advancement of CNI radio architectures. The breadboard PTF translates a 12 MHz wide passband to any frequency from 200 to 300 MHz. The hybrid $LiNbO_3$ device consists of a wideband input transducer and 16 output electrodes, each being programmable in amplitude and sign over a 40 dB range. Bandpass and band-reject responses are demonstrated at 200, 225, 250, 275, and 300 MHz using a manual tap setting procedure. The PTF demonstrates the required capabilities for an integrated CNI system: flexibility, versatility, reconfigurability, and adaptability to varying threat environments. At the same time, it takes advantage of technological advances both in-hand and projected within the near-term future (1985).

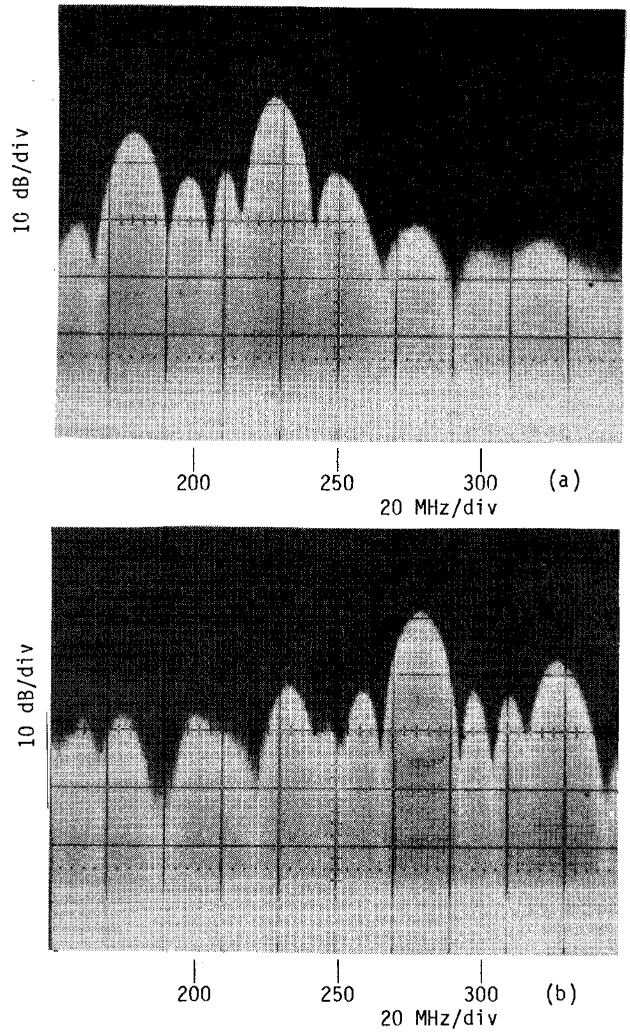


Figure 5. Frequency responses utilizing non-unity tap weights:
(a) 225 MHz response
(b) 275 MHz response

Acknowledgement

The author gratefully acknowledges the helpful discussions with members of the technical staff of the Surface Wave Devices Branch of the Advanced Electronics Laboratory and the Wave Electronics Branch of the Central Research Laboratory of Texas Instruments Incorporated.

References

1. C. M. Panasik et al., in Proc. 1982 National Aerospace and Electronics Conference, E-3, May 1982.
2. C. M. Panasik, in Proc. 1981 IEEE Ultrasonics Symp., pp. 48-52.
3. S. Kwan et al., IEEE Trans. Electron Devices, vol. ED-26, pp. 1053-1058, July 1979.
4. A. J. DeVries et al., in Proc. 1972 IEEE Ultrasonics Symp., pp. 353-358.
5. W. S. Jones et al., IEEE Trans. Sonics Ultrason., vol. SU-19, pp.368-377, July 1972.
6. C. M. Panasik et al., IEEE Trans. Sonics Ultrason., vol. SU-28, pp. 79-91.