DESIGN, FABRICATION AND TESTING OF SAW BUTTERWORTH FILTERS

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Abstract

Techniques for the design and fabrication by direct optical projection of linear-phase, Butterworth-frequency-response SAW filters are presented. Experimental results for a 190 MHz (1.2 μm linewidth) device fabricated on the 40.04 minimal diffraction cut of $Bi_{12}GeO_{20}$ are given.

1. Introduction

There has been considerable attention given recently to the analysis and synthesis of surface acoustic wave (SAW) bandpass filters.[1,2] Much of this work has been directed toward so-called sharp-cutoff filters. That is, those devices having a frequency response with flat passband, narrow transition band, and the lowest possible sidelobes out of band. A typical example is shown in Fig. 1.

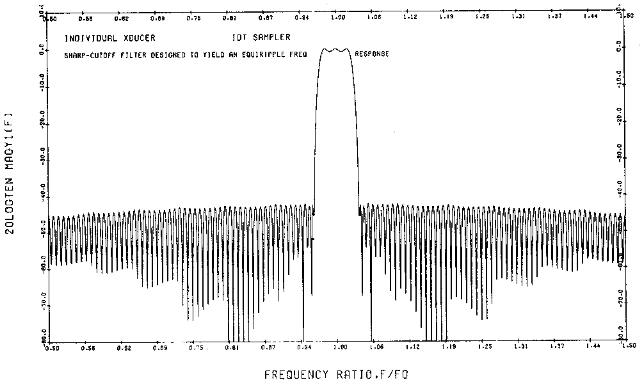


Figure 1 - Example of the ideal frequency response of a so-called sharp-cutoff SAW bandpass filter.

The present paper will, however, be devoted to the design, fabrication and testing of linear-phase SAW Butterworth[3] filters. It is believed to be the first work to deal with this subject. These filters have in the past been synthesized with lumped elements, which makes it difficult to achieve linear phase. An example of an ideal Butterworth frequency response is illustrated in Fig. 2. These gradual falloff characteristics are needed to avoid severe time domain distortion in some frequency measurement applications where the input consists of pulses having spectra of the order of the filter bandwidths.

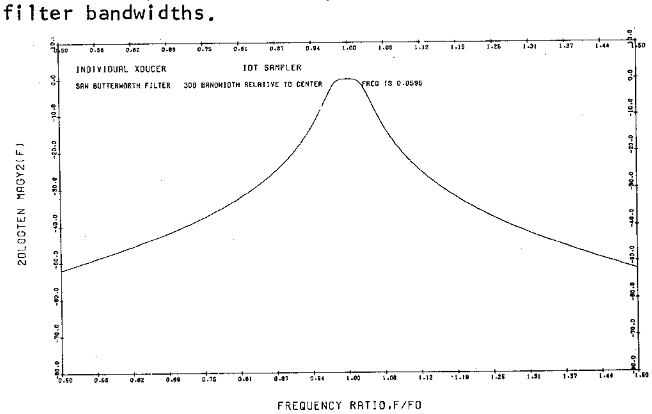


Figure 2 - Ideal frequency response of an 11.3 MHz bandwidth linear-phase SAW Butterworth filter centered at 190 MHz. 158 double electrode pairs needed for realization.

2. Theory of Design

By direct analogy with digital filter design theory,[2,4] a good approximation to the frequency response of a narrowband periodic interdigital transducer is given by

$$H_o(F) = \sum_{k=-M}^{M} H_k e^{-j2\pi kF} = \sum_{k=o}^{M} G_k \cos 2\pi Fk \qquad (1)$$

where $F = fT$ is the normalized frequency, $T = \frac{\Lambda}{2v_s}$ is the sampling interval and the G_k's are directly related to the finger overlap values H_k.

In order to approximate the Butterworth[3] frequency response (having a 3 dB bandwidth, BW; and order, N)

$$|H(F)| = \left[\frac{1}{1+\left(\frac{2F}{T(BW)}\right)^{2N}}\right]^{\frac{1}{2}} \qquad (2)$$

by a summation of the form of equation (1), it is convenient to use a minimax algorithm with Chebyshev polynomials. In this approach the independent variable F must first be mapped onto the interval $-1 \le x \le 1$ by the transformation

$$x = \cos 2\pi F \qquad (3)$$

Thus we can define

$$H_1(x) = \left[\frac{1}{1+\left(\frac{\cos^{-1}x}{\pi T(BW)}\right)^{2N}}\right]^{\frac{1}{2}} \quad -1 \le x \le 1 \qquad (4)$$

as the transform of H(F).

The minimax Chebyshev polynomial approximation[5] to $H_1(x)$ is then given by

$$\hat{H}_1(x) = \sum_{k=o}^{M} G_k T_k(x) \quad -1 \le x \le 1 \qquad (5)$$

where

$$G_o = \frac{1}{\pi} \int_{-1}^{1} H_1(x) T_k(x)\, dx \qquad (6a)$$

$$G_k = \frac{2}{\pi} \int_{-1}^{1} H_1(x) T_k(x)\, dx \qquad (6b)$$

Since

$$T_k(x) = \cos(k \cos^{-1} x), \qquad (7)$$

the coefficients G_k are the same as those of equation (1). The integrals of equation (6) were evaluated using an algorithm which samples the function $H_1(x)$ at the

Chebyshev nodes (zeros of the Chebyshev polynomials). Sampling in this manner yields a good approximation to a minimax fit.

3. Experimental Results

Using the design techniques of the previous section, a set of sampling weights corresponding to the frequency response of Fig. 2 were computed. A photograph of the 10X interdigital transducer used to implement this design is shown in Fig. 3. Double electrodes[6,7] (for the actual device, line widths and gap

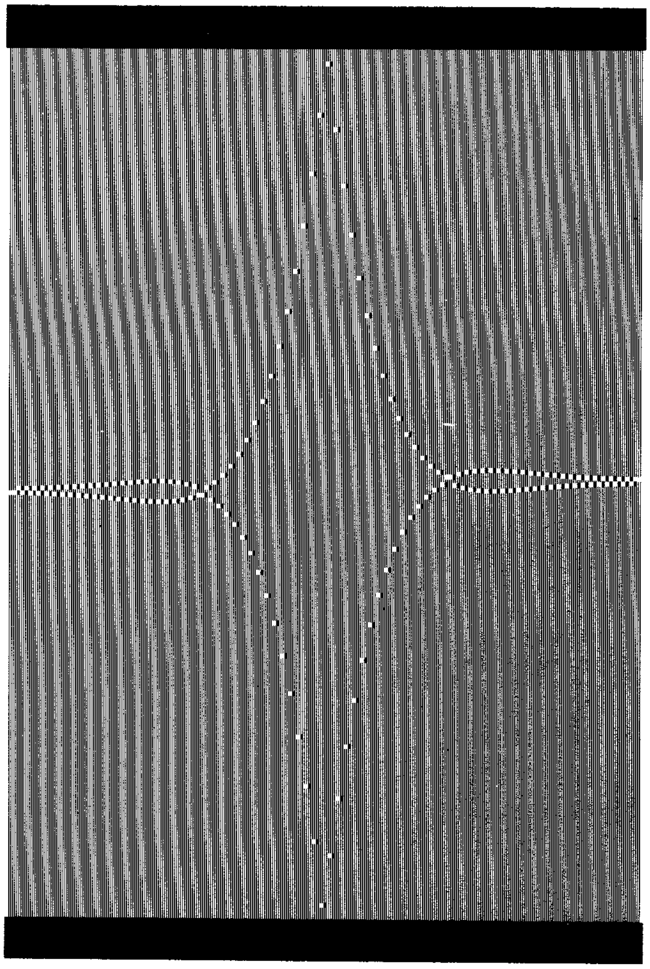
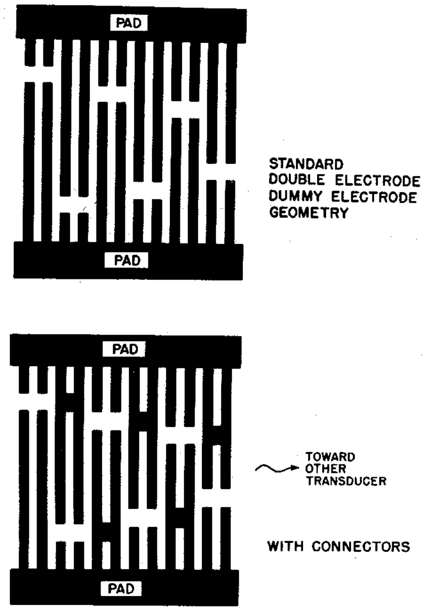


Figure 3 - Photograph of the SAW Butterworth filter having the ideal frequency response illustrated in Fig. 2.

spacings were both 1.2 μm) were used to minimize interelectrode reflections and dummy electrodes[8,9] were used to minimize phase front distortion. In addition, a new technique consisting of connectors between fingers was used to reduce residual phase front distortion caused by the gaps between the electrodes and dummy electrodes. This technique is illustrated in Fig. 4. Finally, in order to eliminate the need for diffraction correction, the actual device was fabricated on the 40.04 minimal diffraction cut[10] (MDC) of bismuth germanium oxide (BGO).

A direct comparison of theory with an experimental spectrum analyzer frequency response curve of a typical device is shown in Fig. 5. All scales are absolute - no normalizations were used. A periodic, unapodized, untuned, output transducer was used in this case in order to allow simple evaluation of the Butterworth response. The computer generated[11] theoretical curve includes all significant second order effects except volume wave generation. Overall agreement between

Figure 4 - Illustration of the use of "connectors" for the reduction of residual phase front distortion caused by gaps between double electrodes and dummy electrodes.



theory and experiment is judged to be quite reasonable for a single, overlap-weighted transducer; particularly since operation at 190 MHz on BGO requires 1.2 μm photolithography. Disagreement occurs mainly at the high frequency end and is attributed to bulk mode generation and interference. Techniques for the suppression of these effects are currently under study.

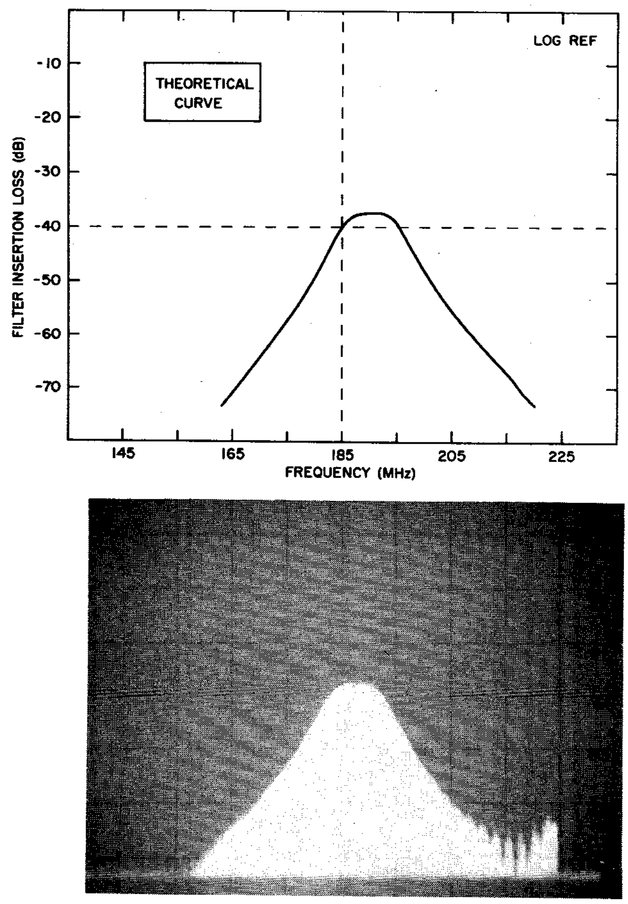


Figure 5 - Comparison of theory and experiment for a 1.2 μm linewidth (overall acoustic wavelength 9.6 μm) double electrode SAW Butterworth filter. Substrate: 40.04 minimal diffraction cut of BGO. 10 dB/div. 10 MHz/div.

4. Device Fabrication

Direct optical projection[12,13] using a 10X master in conjunction with a high resolution 10:1 reduction lens was used to fabricate the SAW Butterworth filters discussed in this paper. The stripping technique[13] which is particularly suited for use with SAW crystalline substrates is also used. That is, a positive photoresist is applied to an uncoated surface and the substrate is then exposed, developed, and a metal deposition of 200-300A of chrome plus 800-1000A of aluminum evaporated. Advantages of this procedure include (1) no mask to substrate contact, (2) no etching of the SAW substrate, (3) elimination of the 1:1 mask fabrication step and (4) only a relatively inexpensive 10X reticle need be purchased. This direct projection system, as illustrated in Fig. 6, consisted of a translation table suitably modified to accept an Ultra-Micro Nikkor 1/10X lens having 650 lines/mm resolution capability and a mercury arc illuminator.

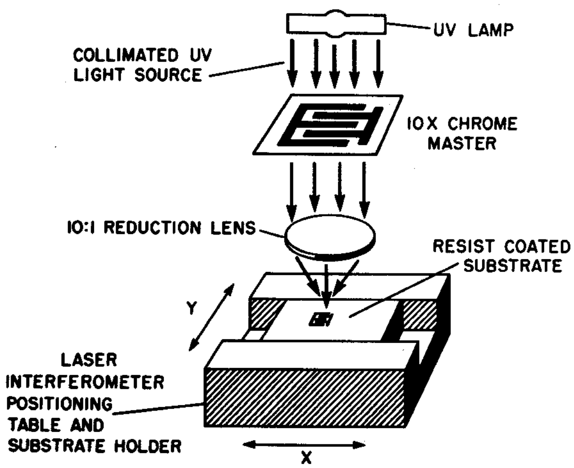


Figure 6 - Schematic drawing of the direct optical projection device fabrication system.

5. Summary and Conclusions

Complete design procedures for the optimum synthesis of linear-phase SAW Butterworth filters have been presented. Using these techniques a 1.2 μm linewidth device was designed and then fabricated by direct optical projection on the 40.04 minimal diffraction cut (MDC) of $Bi_{12}GeO_{20}$. Agreement between theory (including second order effects) and experiment was quite reasonable. The direct projection fabrication technique was described in detail and a new method for reducing residual phase front distortion was introduced.

Acknowledgements

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