PROBLEMS IN THE REALIZATION OF FLAT DELAY, NARROW-BAND SURFACE WAVE FILTERS AT UHF AND MICROWAVE FREQUENCIES

H. Skeie

Electronics Research Laboratory, University of Trondheim
The Norwegian Institute of Technology N-7034 Trondheim-NTH

ABSTRACT

Narrow band filters with maximally flat passband and sharp transitions at the band edges require long transducer arrays. Spesific problems encountered in the construction of such filters are minimization of the number of taps to avoid excessive attenuation and phase distortion, supression of multiple echos, implementation of tap weighting to avoid non-uniform coupling, and numerous problems involved in the fabrication of sufficiently accurate transducer patterns. Tentative solutions to these problems are presented and some experimental results on a 500 MHz, 1% bandwidth filter are given.

Introduction

The realization of maximally flat narrow band filters with sharp band edges traditionally requires the use of coupled resonators with high quality factors. When implemented at higher frequencies, the best results are obtained by means of bulky wave guide cavities. Implementation of these filters by means of acoustic surface waves offers the advantages of greatly reduced weight and size, and also lead to a simplification of trimming procedures. However, the realization of such filters by means of finger transducers imposes very stringent requirements on design optimization and fabrication accuracy.

For example, a filter specified to be flat within 0.2 dB over a 1% passband and with a transition bandwidth of 0.1% would require a transducer structure which is at least 1000 - 1200 wavelengths long. The weakest taps have to be controlled in amplitude within a fraction of a per cent compared to the center taps and the phase delay must be controlled within a small fraction of an acoustic wavelength. For such filters, we are thus talking about positioning accuracies of better than 10^{-5} over the transducer area and of weighting accuracies in the order of 10^{-3}. With very long transducers, the suppression of multiple echos and spurious responses also become a far more serious problem than for shorter structures.

Optimization of narrow band filters

In order to minimize the difficulties involved in the fabrication of long transducers, a primary task in the design procedure is to minimize the transducer length. This is done by optimizing the shape of a time impulse response of a given duration τ_o such that the corresponding frequency response shows a minimal deviation from the desired filter characteristics. By repeating this process for several values of τ_o, a minimum value of τ_o for which the specifications are met, may be estimated. The value of τ_{min} then determines the minimum length of the transducers. In order to minimize the effects of non-uniformities in the metal pattern, and excessive losses due to electrical and mechanical loading of the surface, it is also necessary to further minimize the number of fingers or taps in the transducers. An ordinary (filled) interdigital transducer has a tap separation τ_f corresponding to one half of an acoustic wavelength at the fundamental frequency. This means that the transducer exhibits multiple passbands that are separated by 2fo; fo being the fundamental frequency. If the transducer is "thinned" such that the tap separation is increased by a factor n; the separation between the passbands are reduced to

$$1/\tau = \frac{1}{n\tau_f} = \frac{2fo}{n}$$

The frequency response of a filter based on extensive thinning of one transducer is sketched in fig. 1. In order to suppress the unwanted sideresponses of the main filter transducer, (response R_2) the other transducer has to be designed with stop bands at these frequencies (response R_1). In addition, the external electric matching circuitry may be designed to suppress the far out sideresponses.

Suppression of multiple echos

In long transducer arrays with constant finger spacings, the effect of multiple acoustic reflections from the taps represents a very serious obstacle even for extensively "thinned" transducers. The effect is demonstrated in fig. 2 which shows the frequency response of a 1% bandwidth transducer on lithiumniobate with a thinning factor of n = 13. This effect can be effectively reduced by using split finger electrodes but this requires an increased capability of line resolution in the fabrication "process". A better solution is obtained if passive "dummy" taps are inserted between the active taps. Near perfect cancellation of multiple reflections may then be obtained at the resonance frequency (see fig. 2, curve C_2). However, some ripple is still present unless the dummy taps are properly weighted at the ends of the transducer to obtain acoustic match between the free surface region and the transducer region.

For efficient suppression of triple transit echos without a substantial increase in insertion loss, a configuration with several transducers that are displaced by a quarter-wavelength on the substrate may be employed, see fig. 3.

The displacement is compensated for externally by the use of a quadrature hybrid such that perfect cancellation of the triple transit signal is in principle obtained with a minimum of 3 dB insertion loss.

Weighting methods

When both input and output transducers are weighted, it is neccessary to use methods that prevents a nonuniform shape of the radiated acoustic beam, at least for one of the transdusers. This can be obtained quite efficiently by employing normal apodization in combination with a strip coupler. However, the use of strip couplers is strongly impaired at higher frequencies. Other methods that improve the uniformity of coupling are shown in fig. 4. The method a) which employs a series coupling of elements of constant overlap regions yields a uniform beam at a reasonable distance away from the transducer if the capacitance of the overlap regions is larger than other stray capacitances in the pattern. Unfortunately, this is usually not the case for weakly coupled taps. In method b) the weighting is determined by the amplitude a of the periodic finger displacement:

$$W = \cos k a$$

where k is the propagation factor.

The weighting is frequency dependent which makes it less useful for broad band filters and for weakly coupled taps where a is close to a quarter wavelength.

Fabrication

The requirements of high resolution over a large area necessitates a step and repeat process to be used in the pattern fabrication.

In order to obtain sufficiently accurate translations of the substrate between each exposure, a set up with interferometric control of the movement is needed. It may still be difficult to obtain sufficient accuracy, and the best procedure must be determined from a trade off between the number of steps and the area of exposure in each step. A limiting factor when optical projection through a reduction camera is used, is the unifority of illumination of the substrate. Displacement errors caused by the stepping process can be corrected for after electrical measurements by a trimming of metal strips positioned in the interface regions.

A transducer consisting of many hundreds of fingers will very often come out of the process with a few breaks or shorts, which may seriously degrade the filter performance. We have at our laboratory developed a method for the repair of these faults in the final pattern without having to remake the transducer.

Experimental results

Measurements on a filter with 500 MHz center frequency, 5 MHz passband and 0.8 MHz transition bandwidth are shown in figs. 5 and 6. The filter contained output transdusers that that were approximately 1500 wavelengths long. A "thinning" factor of 55 were used for the active taps. With dummy taps, the transducer thus contained 110 taps.

From time impulse measurements it was found that the attenuation across the transducer was quite large This is demonstrated in fig. 5 which refer to measurements on time sidelobes compared to design values. The curves correspond to an attenuation of 6 - 7 dB across the transducer. We believe most of this loss must be ascribed to surface wave - to bulk wave conversion due essentually to mass loading at the fingers.

Results from measurements on the passband response is shown in fig. 6. Most of the fine structure ripple is due to a combination of direct feed through and triple transit signals. The sharply assymetric behaviour at the center frequency is believed to be due to a somewhat insufficient suppression of multiple reflections in the transducer structure which again can be traced back to differencies in geometry of active taps as compared to dummy taps. The course variation is due to displacement errors corresponding to some 10 degrees of phase or 0.2μm in the close in sidelobes of the weighting function.

Conclusion

The surface wave technology offers interesting solutions to the problem of realizing light weight narrow passband filters in the UHF to lower microwave region. The problems of design and fabrication, however, becomes increasingly difficult for these filters at higher frequencies, and they do not presently compete favourably with conventional cavity filters with respect to performance.

It is possible that filters based on the technique of ion beam etched reflecting arrays [3, 4] could yield a somewhat improved performance, possibly by employing a combination of longitudinal (resonator type) and transversal filter functions.

References

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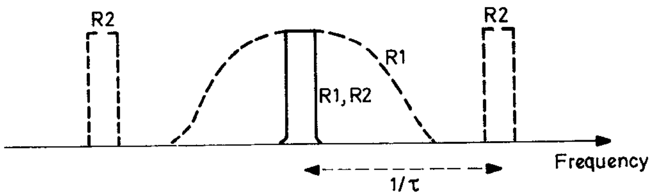

Fig.1. Frequency response of thinned transducers.

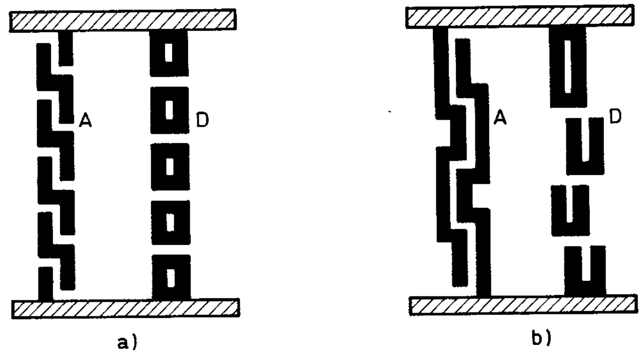

Fig.4. Methods of distributed tap weighting.
a) Series coupling, b) position weighting.

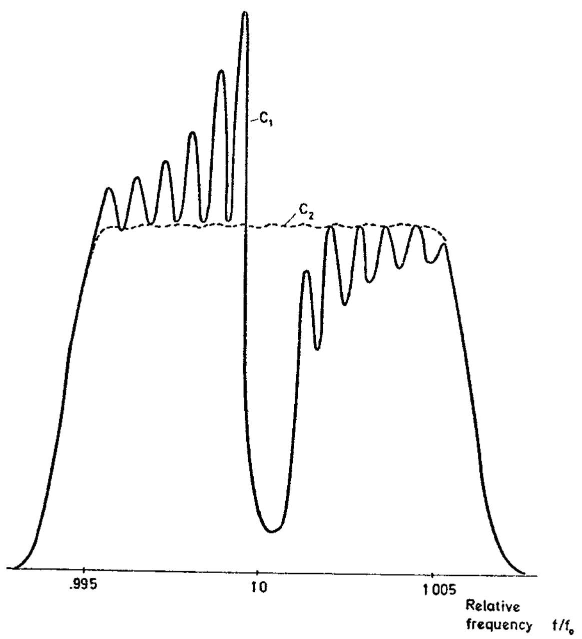

Fig. 2. Effect of multireflections on lithium niobate.

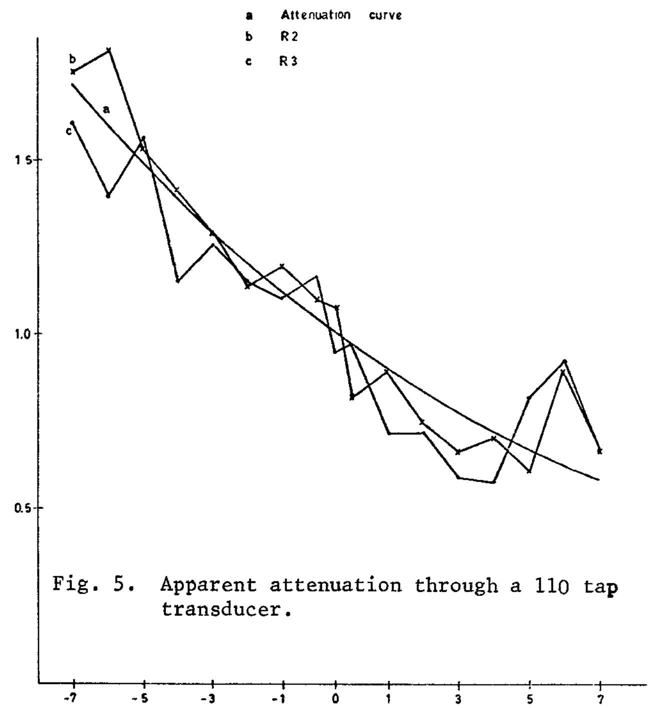

Fig. 5. Apparent attenuation through a 110 tap transducer.

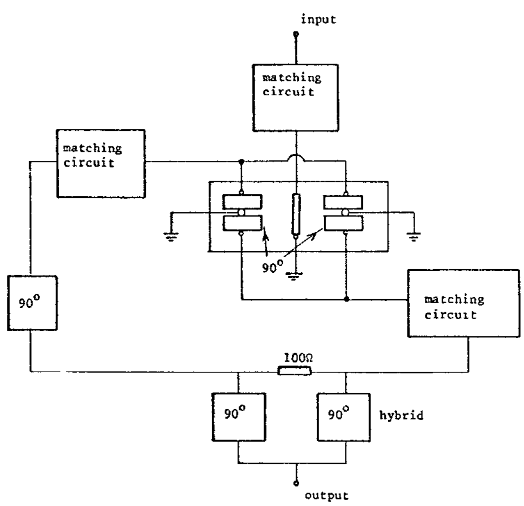

Fig. 3. Surface wave filter with displaced transducers and external compensation thorugh hybrid.

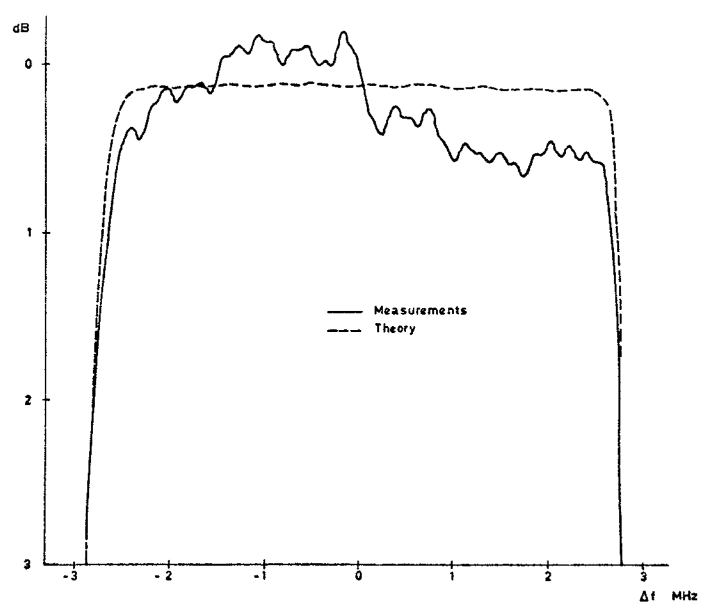

Fig. 6. Passband response of a 500 MHz center frequency, 5 MHz bandwidth filter.