WEIGHTED UNIDIRECTIONAL TRANSDUCER SAW FILTER AT 328 MHz

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ABSTRACT

The first UHF, finger withdrawal weighted, unidirectional transducer surface acoustic wave (SAW) filter is reported in this paper. It has only 4.5 dB insertion loss at 328 MHz and a 1 percent bandwidth. The filter has -48 dB sidelobes and greater than -50 dB triple transit suppression.

INTRODUCTION

Conventional SAW filters are being utilized in a remarkable number of signal processing systems in the VHF and UHF frequency range because of their superior performance, flexibility of function, compactness, reliability, and low cost compared to lumped element and crystal filters. Applications include bandpass filters, dispersive filters, phase coded matched filters and delay lines.

Biphase, interdigital surface wave transducers have two basic flaws when employed in filter applications. The first is their relatively high insertion loss compared to crystal or lumped and distributed electromagnetic filters. The conventional "low loss" design still has 7 to 10 dB of insertion loss. 6 dB of this loss is caused by the biphase property of the transducer with 3 dB of loss incurred at each transducer and the rest is due to parasitics. The conventional design also has triple transit echos due to regeneration at each transducer. These echos may cause ripple in the magnitude response as much as several dB and ripple in the phase response is also a result. Consequently, biphase SAW devices are frequently mismatched to as much as 20 dB to reduce triple transit echos to reasonable levels. Reducing the insertion loss and triple transit signal found in biphase devices would further enhance the performance of acoustic surface wave filters in all systems, and particularly in applications where low insertion loss is mandatory for low noise figures, efficiency, or large dynamic range. Such applications include receiver front-end filters and interstage and output filters for RF transmitters.

This paper presents the first three phase unidirectional transducer employing finger withdrawal weighting.[1] As shown in Figure 1 crossovers are necessary and each electrode is driven 120° out of phase and there are three electrodes per wavelength on the substrate.[2] The filter has only 4.5 dB insertion loss and essentially no triple transit with -48 dB sidelobes. Sources of insertion loss are discussed in the design of the filter. Weighting techniques, packaging, matching and fabrication are also discussed.

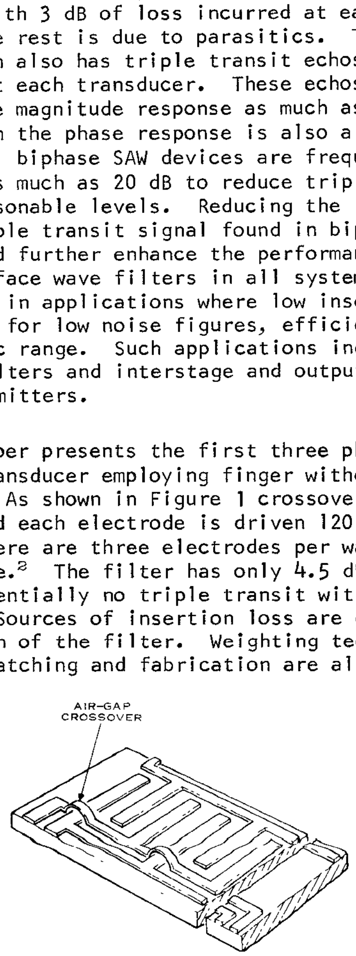


Figure 1. Multilevel Unidirectional Transducer Structure.

FILTER DESIGN

A. FILTER SPECIFICATIONS

Table I

Filter Specifications

Center Frequency	328 MHz
Bandwidth (3 dB)	3.3 MHz
Shape Factor (3 dB to 40 dB)	1.5
Bandpass Ripple	.5 dB MAX
Midband Insertion Loss	4 dB MAX
Input-Output Impedance	50 Ω matched
Sidelobe Level	50 dB
Spurious Rejection	>50 dB
Triple Transit Suppression	>50 dB

The low loss filter specifications are presented in Table I. Texas Instruments has repeatedly achieved the specifications presented here for conventional bandpass SAW devices. This does not include however, the insertion loss and the triple transit levels shown. Insertion loss contributions are the prime consideration in the design of the filter and will be discussed in the following section.

B. LOSS MECHANISMS

The object of the design exercise of the filter is to trade-off various contributions to insertion loss to minimize the total loss and still achieve the other specifications of the filter. Before any other calculations can be performed, the length of the transducer must be calculated based on the transition bandwidth of the filter, i.e., the steepest skirt. In the case of the shape factor of 1.5 at 330 MHz and a bandwidth of 3.3 MHz the transition bandwidth is 1.08 MHz. From reference 3

$$\tau_{MIN} \approx (.73/B_1) \log R_2$$

Then the length of the transducer is 1.69 μsec or .210 inches.

1. Propagation Loss. Knowing the transducer length the propagation loss may be accurately calculated from information published by Slobodnik.[4] With .050 inches between the transducers the propagation path distance is .260 inches. According to reference 4 propagation loss at 1 GHz is 3.09 dB/μsec for ST quartz. This loss goes as f^2 giving .34 dB/μsec at 328 MHz. Total loss due vacuum attenuation is then .713 dB. Air loading adds .155 dB of loss giving a total propagation loss of .87 dB.

2. Diffraction Loss. The beamwidth of the transducer was chosen so as to trade diffraction loss off against parasitic finger resistance loss. Minimum loss was found to be at a beamwidth of 66 wavelengths. From the diffraction curves of Szabo[5] diffraction and beamspreading loss for this device on ST quartz is .8 dB.

3. Parasitic Finger Resistance. The loss due to finger resistance now may be calculated knowing the beamwidth of the device. The beamwidth is 66 wavelengths or .025 inches. Each finger is 1/6 wavelength, therefore the total number of squares per finger is 400. Assuming 1200 Å of aluminum, the sheet resistivity is .3 ohms per square. This leaves each finger at 147 ohms. With a total of 451 wavelengths and using a factor of 2/3 because there are three fingers per wavelength, the total parasitic finger resistance is .22 ohms. The radiation resistance and parallel capacitive reactance may be calculated using equation (27) of reference 3. The time-bandwidth product used here is 4.5. The radiation resistance is then 151 ohms and the parallel capacitive reactance is 20 ohms. The series acoustic resistance is then 2.6 ohms and the series reactance is 19.6 ohms. Loss due to the parasitic resistance is then .7 dB per transducer or a total of 1.4 dB.

4. Crossover Capacitance. The capacitance due to the corssovers must be made small in comparison to the finger capacitance. The simple parallel plate equation is accurate enough for the purposes of this design.

$$C = \frac{\epsilon_o A}{\ell}$$

With an air gap of 4000 Å and a crossover bussbar width of .001 inch the crossover capacitance is 8.9×10^{-4} pico farad per crossover. The finger capacitance is 3.49×10^{-2} pico farad. Therefore the crossover capacitance is negligible.

5. Matching Network Loss. The Q of the matching network components is about 80. Because the radiation Q of the device is about 4, the matching networks will cause .5 dB of insertion loss per transducer for a total of 1.0 dB.

6. Other Losses. The crossover bar will need to be narrow to allow etching away material to form the air gaps. However, it must not have too much resistance because of the added parasitic resistance to one phase of the device. If the bar could be made to have a resistance of 1.4 ohm. The average finger would see about .4 ohm. If we average this over the 3 phases we have .13 ohm. For a three phase system the effective resistance is .090 ohm. The added insertion loss is .3 dB per transducer or .6 dB for the filter.

Based on the above calculations the filter should then have a loss of 4.67 dB. This could easily vary depending on actual finger thickness and width and resistance of the gold crossover bar. Also, the surface quality of the quartz could cause the propagation loss to vary.

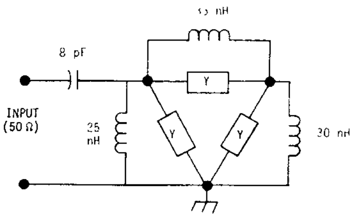
C. FINGER WITHDRAWAL WEIGHTING

Finger withdrawal weighting[1] realizes a desired filter transfer function by selectively removing electrodes from an interdigital array which had uniform overlap. Finger withdrawal weighting has been adequately discussed in the literature[1] so an in depth discussion is not necessary here. To emphasize the basic design rule: "Minimize the difference between the integrals of the desired envelope (of the time response) and the withdrawal envelope."[1]

Withdrawal weighting is ideally suited for a three phase unidirectional transducer. Whereas, overlap weighting would be much more difficult to implement. Both methods are sensitive to broad bandwidths and will work best with narrow band transducers. Because of ease of implementation the withdrawal weighting technique was employed in the design of this filter.

D. MATCHING AND PACKAGING

The final circuit configuration of the 330 MHz unidirectional transducer is shown in Figure 2. The components were derived by an iterative matching technique discussed by Brown.[6] The admittances shown as Y in the circuit are the parallel combination of the acoustic radiation resistance finger capacitance for each phase. The S-parameters were measured for one transducer of this device by using 2-port measurements with the third port grounded. At these frequencies, parasitics could influence the accuracy of the data significantly, so great care was taken to minimize or cancel their effects on the data. The corrected measurements obtained at the center frequency (328 MHz) were as follows: S_{11} - S_{ZZ} = 1.9 dB at a phase angle of -105° and S_{12} = S_{21} = -6.8 dB at a phase angle of -24°. This data was then used with the matching program to obtain theoretical matching component values. Despite the care taken in getting accurate S-parameter measurements, there were still considerable package parasitics, primarily due to the package feedthroughs, which added reactance of almost the same magnitude as that of the device itself. Therefore, the inductance and capacitance values had to be adjusted in order to cancel the parasitic effects and optimize device performance.



NOTE The unidirectional transducer is represented by the three admittances (Y) shown above

Figure 2. Matching Network used with 328 MHz Unidirectional Bandpass Filter.

Each matching network was completely shielded from the other by the use of separate compartments. To reduce parasitics RF feedthroughs were used and gold ribbon was employed for bonding to the device instead of aluminum ultrasonic bonding. A shield was also used between the transducers to reduce crosstalk even further.

E. FABRICATION

Fabrication of the three phase unidirectional transducer utilizing air insulated crossovers was described by Rosenfeld.[2] The steps in the fabrication process include (1) defining the aluminum finger pattern on the substrate, (2) sputtering a layer of moly and etching the via holes, (3) sputtering titanium tungsten-gold, (4) electro-chemically plating thick gold crossovers, (5) and etching away the moly to leave the air insulated gold crossovers. Figure 3 shows an SEM of the air insulated crossovers.

To reduce the number of electrodes requiring an air-gap crossover two active fingers were connected to each electrode requiring a crossover. A photo of this is shown in Figure 4. The inside buss bar is the grounded phase and the other buss is one of the two ungrounded phases.

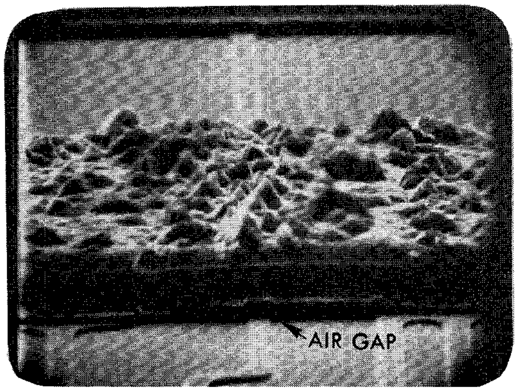


Figure 3. SEM Showing Aluminum Finger and Gold Crossover.

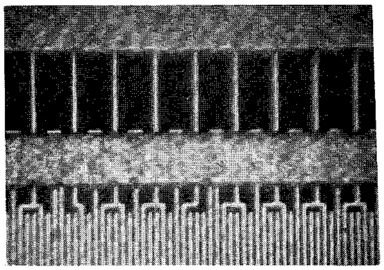


Figure 4. Photo of the Crossover Reduction Technique.

DEVICE PERFORMANCE

The magnitude versus frequency response of the filter is shown in Figure 5. It has an insertion loss of 4.5 dB and sidelobes at -48 dB. The triple transit level is not measurable (< 55 dB). A major portion of the insertion loss (~ 2 dB) is due to parasitic resistance in the fingers and the gold crossover buss bar. The rest of the loss is due to propagation loss (.9 dB) diffraction (.8 dB) and the matching networks (1.0 dB).

Insertion loss for this particular unidirectional filter could be reduced further by (1) increasing the thickness of the aluminum on the fingers and (2) increasing the thickness of the gold on the crossovers. This would reduce the loss to about 3.0 dB.

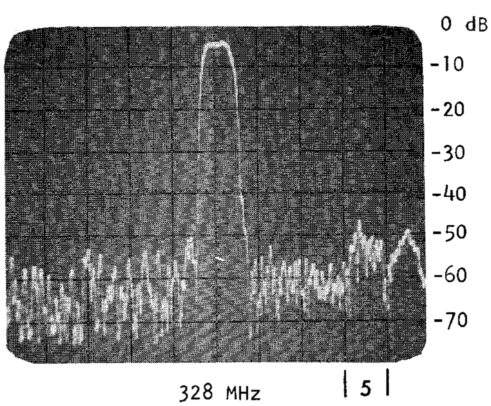


Figure 5. Response of the 328 MHz Unidirectional SAW Filter Showing 4.5 dB of Insertion Loss.

SUMMARY

In summary, the first low insertion loss, unidirectional transducer to use finger withdrawal weighting is reported in this paper. It was constructed on Quartz and has a 1.0 percent bandwidth at 328 MHz, the highest frequency reported for a unidirectional surface acoustic wave filters. This filter utilizes the 3 phase transducer design with 3 electrodes per wavelength, each 120 degrees out-of-phase with its nearest neighbor. When a three-phase source is applied to the sets of electrodes, the acoustic surface waves add constructively in the forward direction and destructively in the other direction.

Performance of the filter is excellent in that it has only 4.5 dB of insertion loss and no triple transit with good sidelobe characteristics. The ultimate insertion loss for this particular filter is about 3 dB, however, filters requiring wider transition bandwidths and higher shape factors could have as low as 2 dB insertion loss at 300 MHz. At such low insertion losses the possible applications include RF receiver front end filters and low loss IF filters.

ACKNOWLEDGEMENT

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