Reduced Sidelobe Integrated Acoustooptic Filter using Birefringence Apodization

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AOTF, acoustooptic filter, lithium niobate, integrated optics

A two-section integrated acoustooptic tunable filter with significantly reduced sidelobes has been fabricated. The sidelobe reduction was achieved using birefringence apodization in the form of variable width Ti stripe waveguides. The design and fabrication of the device, which includes integrated proton exchanged TE and TM pass polarizers, is described. Experimental tuning curves for each filter section and the overall device are presented and compared with calculated results. The largest sidelobes were found to be 24 dB below the peak transmission, representing a 5.3 dB improvement over an ideal filter without birefringence apodization. The FWHM of the filter is 1.36 nm, which is only 16% larger than predicted for its interaction length of 17 mm per section.

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INTRODUCTION

Integrated acoustooptic tunable filters (AOTF's), which act as electronically tunable narrow bandpass optical filters, have numerous potential applications. Perhaps the most important use for AOTF's is for wavelength division multiplexing (WDM) in telecommunications systems. A significant limitation of simple AOTF designs is the presence of large sidelobes in their transmission spectrum. A simple one section device is calculated to have sidelobes which are only about 9.3 dB below the center frequency transmission.[1] Such large sidelobes would lead to unacceptable levels of crosstalk between channels in a WDM system.

Cascading two filter sections has been proposed and demonstrated[2,3] to reduce sidelobes, and should ideally reduce their levels to -18.6 dB, although further reductions by this method become limited by substrate size. Sidelobes may also be reduced by interaction strength apodization (controlling the acoustic power along the device length) and has been demonstrated by two different techniques.[4,5] The benefits of this technique, however, come at the expense of a 37% increase in the filter's 3 dB bandwidth due to the reduced effective interaction length and a 250% drive power increase. Significant increases in the spectral bandwidth of a filter would, of course, limit the number of channels in a WDM system.

Experimental results for all types of AOTF's have generally shown much larger (and highly asymmetric) sidelobes than would be predicted by theory. These results have recently been shown to be due to variations in the effective birefringence along the length of the device which are symmetric with respect to the center of the active section. These variations may be caused by thermal gradients or waveguide non-uniformities.[6,7] Symmetric birefringence variations raise the sidelobes on either the short or long wavelength side of the filter function and reduce them on the opposite side. It was noted that intentional birefringence variations of opposite signs in a two section device can be used to reduce sidelobes below that possible with a uniform device.[6] These results show that sidelobes may be reduced to -30 dB with only a 5% bandwidth increase and negligible increases in drive power. In this letter, we demonstrate this technique using a device with integrated polarizers and report sidelobe levels of less than -24 dB which are far less than those possible in a device with uniform birefringence.

DEVICE

The reported device was fabricated in x-cut y-propagating $LiNbO_3$ and consists of two 17 mm long interaction regions between integrated TE and TM pass polarizers as shown in Figure 1. Titanium diffused waveguides are used in the active regions of the device. The Ti thickness was 1075Å and was diffused for 6 hr. at 1050°C in wet O_2. In the previously proposed birefringence technique,[6] the waveguide width is graded continuously. Due to limitations in the photomask fabrication equipment, the waveguide widths used this experiment were rounded to 0.2 μm steps. This results in only 5 different width guide regions in each section of the device. The layout of the both sections are shown in the graph in the lower part of Figure 1. The difference between the end widths of these sections is made up by tapering the width of the guide in the inactive region connecting them.

The reduction in sidelobe suppression using these discrete width steps relative to a continuous variation was calculated and found to be insignificant. In fact, it was found that results were not very sensitive to the exact waveguide profile as long as each section has even variations of birefringence of opposite signs. Care must be taken, however, to avoid uncontrolled variations in the waveguide width and Ti thickness during fabrication which could wash out the desired effect.

The TE pass polarizers are 4 mm long sections of annealed proton exchanged (APE) waveguide (width = 6 μm) butt coupled to the titanium stripe guides in the active region.[8] Since proton exchange raises the extraordinary index but lowers the ordinary index of the substrate, APE waveguides only supports the TE mode on the crystal cut used in this device. The fabrication parameters for these guides are chosen to give good mode matching to the titanium diffused waveguides. The TM pass polarizers are formed by a heavier proton exchange in regions adjacent to the guide with zig-zag outer boundaries.[3] Our TM-pass polarizers differ from those in ref. 3 in that no anneal is used. Both types of polarizer achieve extinction ratios in excess of 30 dB, which should not present a limitation for the expected sidelobe levels.

There are two 10-pair split finger interdigitated transducer electrodes in each sections. The second electrode in each section is used only for SAW diagnostics. The electrode is designed for an acoustic center wavelength of 20 μm which yields a optical center wavelength of about 1.55 μm. The use of 10-pair electrodes rather than 5-pair as in our previous devices reduces coupling to bulk acoustic modes. The more efficient coupling reduces birefringence problems associated with thermal gradients. In addition, the device was waxed to an aluminum block rather than a fiberglass printed circuit board which was done in earlier experiments.[6] This further reduces the thermal gradients by improving the heat sinking. The device was cut with 7° angled endfaces to avoid back-reflections, which is important for many applications.

EXPERIMENTAL RESULTS

The filter was tested at a wavelength of 1.55 μm using an HP 8168A Tunable Laser Source coupled into the guide using Corning PRSM™ polarization preserving fiber. The fiber output is set to the TE polarization for efficient coupling. Because of the discrete nature of the waveguide steps, the two device sections have slightly different center frequencies. In addition, linear gradients of birefringence can shift the center frequencies of the two sections. For this reason, the device is mounted on two Peltier coolers, one under each section, which allows the two sections to be temperature tuned into coincidence. This typically required a temperature difference of less than 2°C.

Filter response was measured by varying the drive frequency rather than the laser wavelength, although both methods are equivalent. The tuning curve of each section was measured separately by driving the opposite section with its peak transmission frequency. Figure 2 shows the tuning curve for each section, along with the theoretical curve calculated using the fabricated waveguide profile. Reasonable agreement with theory was found, particular in the back section of the device (lower portion of Figure 2). Disagreements between experiment and theory is probably due to small process related variations in the waveguide birefringence.

When both sections were scanned together, as would be done in normal operation, the tuning curve shown in Figure 3 was obtained. The largest sidelobe was 24 dB below the peak which, to our knowledge, is the best value achieved to date by any technique. For comparison, the dashed line in Figure 3 indicates the minimum theoretical sidelobe level in a two-section unapodized device. The background sidelobe level of approximately -30 dB indicates that the polarizers indeed achieve that level of extinction.

The 3 dB bandwidth of the measured data is 152 KHz corresponding to 1.36 nm in wavelength. This bandwidth is only 16% wider than that for an ideal unapodized device (1.14 nm). The predicted bandwidth of the present device is 1.19 nm. The small difference with experiment can again be attributed to small residual linear gradients in the waveguide birefringence. The transducer power required to achieve complete coupling was approximately 100 mW, which was the same as for unapodized devices of similar design.

CONCLUSIONS

We have demonstrated an acousto-optic tunable filter using birefringence apodization and integrated polarizers to reduce sidelobes to less than -24 dB which is 5.3 dB below that possible with unapodized devices. This was achieved without significant power or bandwidth penalties. Further refinements of this technique should allow reduction of sidelobes to approximately -30 dB. Further reduction would most likely require additional filter stages.

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Figure Captions

Figure 1. (Top) Two section acousto-optic filter with integrated polarizers. (Bottom) Titanium diffused waveguide width in each section as a function of length.

Figure 2. Measured tuning curve (crosses) of each section of the birefringence apodized device compared with theory (solid line) for the variable width waveguide with discrete step width. Wavelength is fixed at 1.55 μm and acoustic drive frequency is varied. (top) First section response. (bottom) Second section response.

Figure 3. Comparison of measured tuning curve (crosses) of two-section birefringence apodized device with theory (solid line) for the variable width waveguide with discrete step width. Dashed line indicate minimum sidelobe levels possible with a two-section uniform interaction device. Wavelength is fixed at 1.55 μm and acoustic drive frequency is varied. FWHM of measured data is 152 KHz corresponding to 1.36 nm in wavelength.

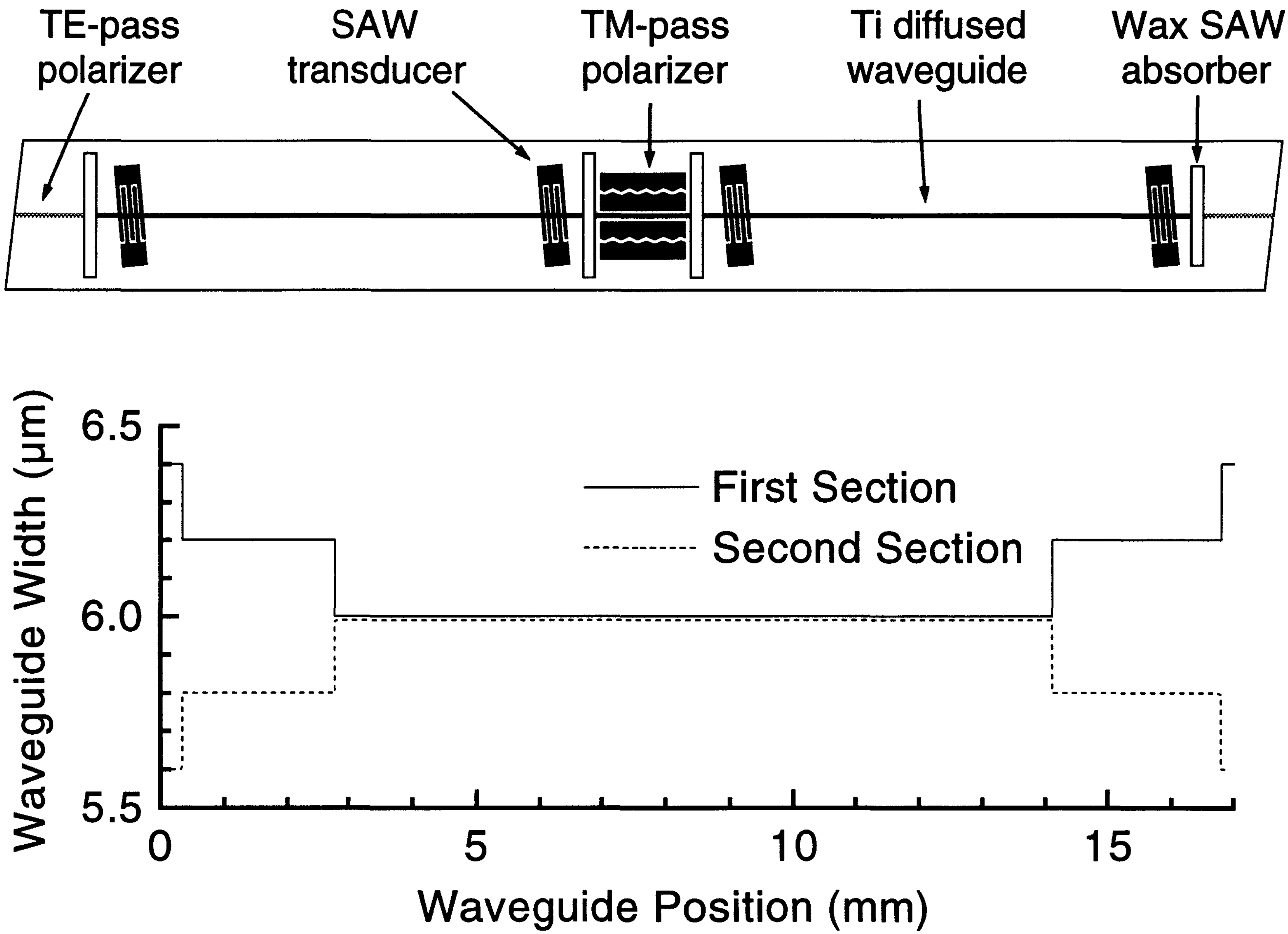
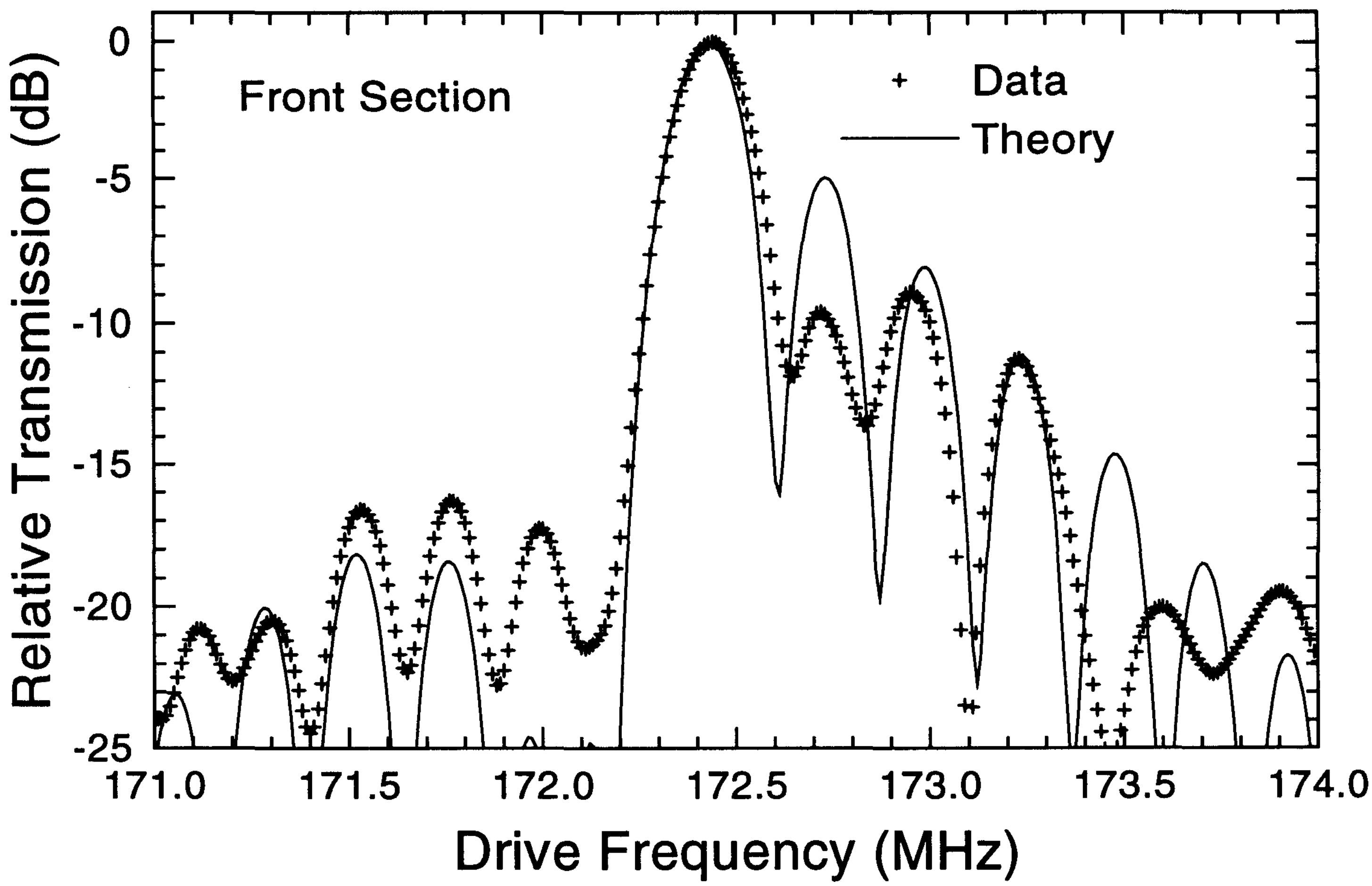
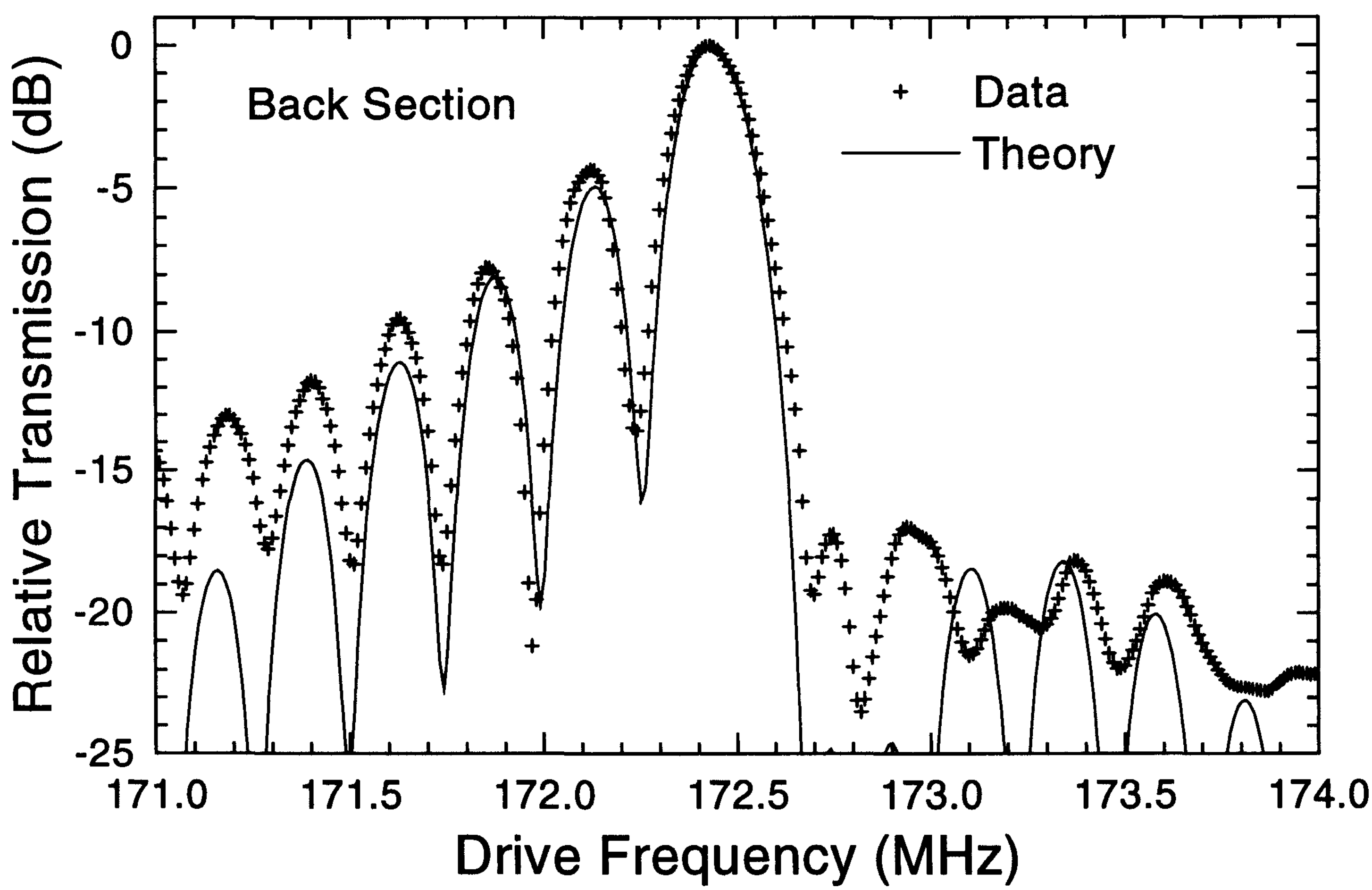

TE-pass
polarizer
SAW
transducer
TM-pass
polarizer
Ti diffused
waveguide
Wax SAW
absorber
First Section
Second Section
Waveguide Width (μm)
6.5
6.0
5.5
0
5
10
15
Waveguide Position (mm)

Figure 1


Front Section
Data
Theory
Relative Transmission (dB)
0
-5
-10
-15
-20
-25
171.0
171.5
172.0
172.5
173.0
173.5
174.0
Drive Frequency (MHz)


Back Section
Data
Theory
Relative Transmission (dB)
0
-5
-10
-15
-20
-25
171.0
171.5
172.0
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173.0
173.5
174.0
Drive Frequency (MHz)

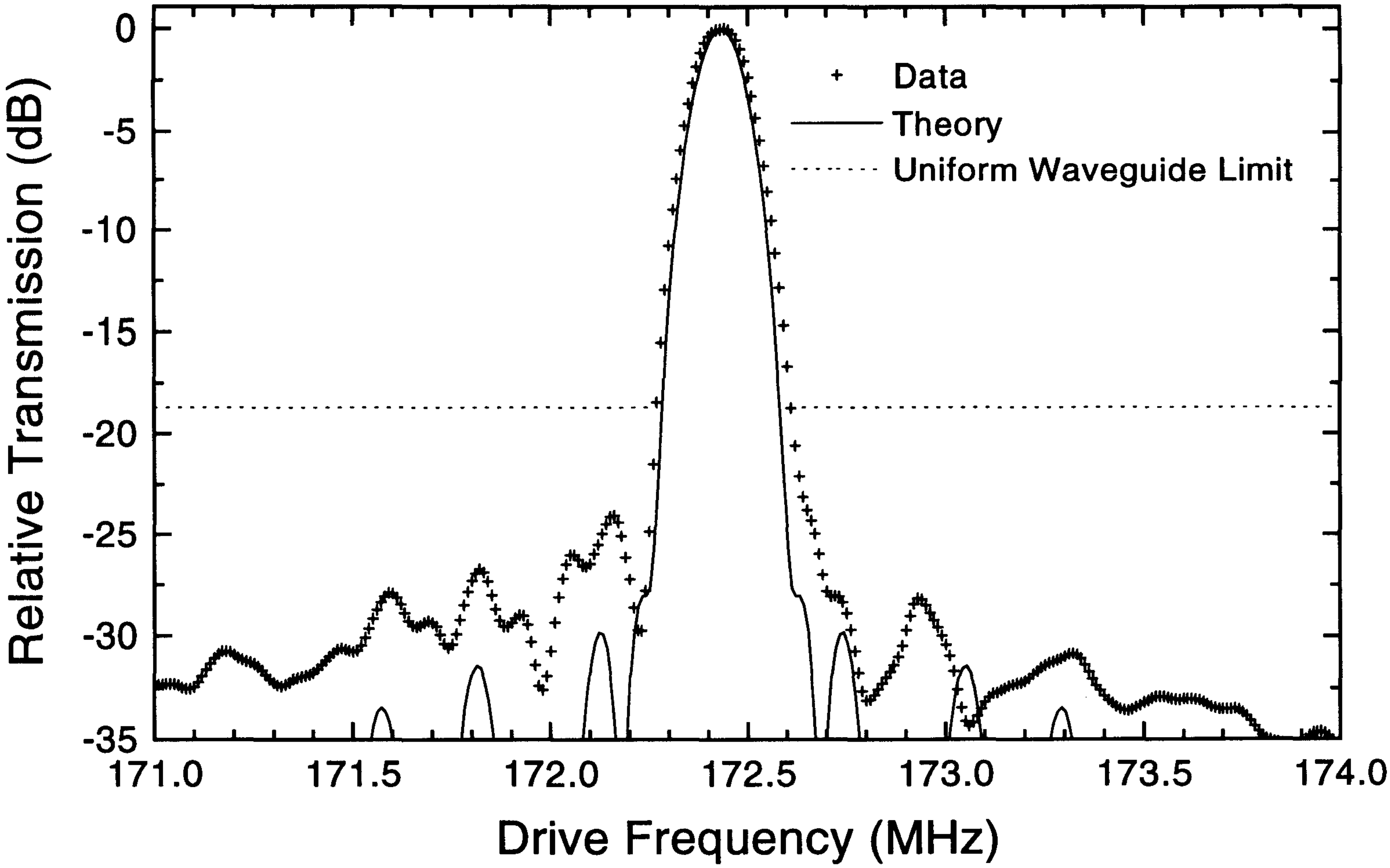
Data
Theory
Uniform Waveguide Limit
Relative Transmission (dB)
0
-5
-10
-15
-20
-25
-30
-35
171.0
171.5
172.0
172.5
173.0
173.5
174.0
Drive Frequency (MHz)

Figure 3