Alhaider

A HIGH PERFORMANCE ACOUSTOOPTIC GUIDED-LIGHT BEAM DEVICE USING INTERSECTING SURFACE ACOUSTIC WAVES*

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ABSTRACT

An acoustooptic guided-light beam device utilizing two surface acoustic wave interdigital transducers, which are staggered in their center frequency and tilted in their propagation direction, on an essentially single-mode optical guiding layer of a Y-cut $LiNbO_3$ substrate has been shown to be capable of providing a very wide bandwidth. Detailed measurements on the diffraction efficiency and the deflection angle of the light beam versus the frequency of the driving signal using a 6328 Å He-Ne laser light are presented. The measured bandwidth of the device is 185 MHz, which is more than an order of magnitude larger than that obtained in previous devices, with the measured electric driving power of 200 mw for 50% diffraction efficiency. The new device configuration introduced here should be very useful for wideband applications such as a guided-wave acoustooptic rf spectrum analyzer and high-speed multiport switches for fiber/integrated optics.

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Acousto-optic guided-light beam devices will certainly serve important functions such as modulation, switching and deflection of a laser beam in future thin-film and fiber optics systems. In accordance with this expectation, there has been a very active interest with this type of device in recent years.(1-11) However, to the best of our knowledge, all of the various forms of acousto-optic guided-light beam devices, namely, modulators, switches and deflectors which had been reported heretofore employed only a single surface acoustic wave (SAW) interdigital transducer to generate a single acoustic beam.(1-11) As a result, they suffer from either a relatively low diffraction efficiency or a relatively small bandwidth. The inherent limitation with a single transducer is that in order to achieve a large device bandwidth (assuming a transducer electric bandwidth sufficiently larger than the Bragg bandwidth) the aperture of the transducer must be chosen very small which in return results in a drastic decrease in the diffraction efficiency.(12) Under such an unfavorable condition a device with both large diffraction efficiency and large bandwidth requires a large rf driving power which in return may easily result in the failure of the interdigital transducer. A further limitation of which the interdigital transducers suffer is the trade-off between the electrical bandwidth (which is inversely proportional to the number of finger electrode pairs) and the electrical-acoustic conversion efficiency (which is proportional to the square of the number of finger electrode pairs).(13) Thus, all of the previous devices employ a single SAW transducer with a relatively large number of finger electrode pairs resulting in a very small bandwidth.(1,3,5,7,9)

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In this paper the experimental results of an acoustooptic guided-light beam device utilizing a new device configuration are presented. The main idea behind this new device configuration is the utilization of multiple intersecting SAW transducers, which are staggered in their center (operating) frequency and tilted in their propagation direction, to simultaneously achieve both a large diffraction efficiency and a large bandwidth. The tilting angle between the adjacent transducers is determined by the difference in the Bragg angles at their center frequency. In the results to be presented below the device utilizes two intersecting surface acoustic waves propagating on a Y-cut $LiNbO_3$ substrate. Y-cut $LiNbO_3$ substrates were chosen because of their large electromechanical coupling coefficient, moderate acoustooptic figure of merit, and the applicability of the out-diffusion technique for the fabrication of the optical waveguiding layer.(7,14) Detailed measurements for the device include the diffraction efficiency as well as the deflection angle of the light beam versus the frequency of the driving signal using a 6328 Å He-Ne laser light.

The configuration of the device being studied is shown in Fig. 1. An optical waveguiding layer having one to two TE modes was formed on a Y-cut $LiNbO_3$ plate using the out-diffusion technique. Two interdigital SAW transducers having the designed center frequencies of 255 MHz and 382 MHz, respectively, and an intersecting angle of approximately 0.3 degrees were fabricated on the top of the waveguide to generate two intersecting acoustic beams propagating approximately along the z-axis of the $LiNbO_3$ crystal. Each of the two transducers consists of two and a half pairs of interdigital finger electrodes and, therefore, can easily provide a bandwidth of more than 40% of its center frequency. The apertures of the two transducers are 1.66 and 1.11 mm, respectively, each being large enough to insure the individual diffraction to be in the Bragg regime. The two transducers were connected in parallel and their combined electrical capacitance was tuned out with an inductance. The measured frequency response of the Bragg diffraction efficiency with two acoustic beams excited simultaneously, together with that of the two acoustic beams excited separately are shown in Figs. 2b and 2d. The corresponding wideband electrical response of the transducers are shown in Figs. 2a and 2c. From Figs. 2b and 2d it is seen that this resultant device bandwidth (185 MHz) is larger than the sum of the device bandwidth using acoustic beam #1 alone (85 MHz) and the device bandwidth using acoustic beam #2 alone (75 MHz). It is important to observe that the measured bandwidths which correspond to the separate excitation of the acoustic beams are considerably smaller than the calculated device bandwidths based on the formula as given in Eq. (36) of Ref. 12 which is 182 MHz for both acoustic beams. A theoretical study which aims at verifying this large difference is in progress. It should also be observed that the diffraction efficiency peaks in a neighborhood of the transducer center frequencies, namely, 225 MHz and 382 MHz as expected. A flat response, instead of a dip, between the two peaks would be expected if the center frequencies of the two transducers were separated by a smaller amount that the one implemented. As a matter of fact an additional peak, located between the two peaks, was observed in an earlier design in which the separation of the two center frequencies, 170 MHz and 200 MHz, was considerably smaller.[(15)] In this earlier version a resultant device bandwidth of 60 MHz was obtained. Similar frequency responses with the resultant device bandwidth varying from 155 MHz to 195 MHz were also obtained as the incident angle of the light beam was varied by approximately $\pm 25'$ from the optimum Bragg condition. The same is true with Fig. 2b. Further increase in the resultant device bandwidth should be achievable by adding more transducers at the appropriate center frequency and intersecting angle.

In a beam deflection application a 185 MHz device bandwidth will provide 530 resolvable spot diameters with a transit time of 2.8 microseconds for a light beam aperture of 1 cm. (The relevant surface acoustic wave velocity is 3.5×10^5 cm/sec.)

Fig. 3 shows the photograph of the deflected spots as the frequency of the driving signal was varied from 240 MHz to 420 MHz for a light beam aperture of about 0.1 cm. With such a relatively small light beam aperture no degradation of either the undiffracted or the diffracted light beam was observed. The number of resolvable spot diameters agrees well with the calculated value. In the device being studied a light beam aperture of 0.4 cm with some nonuniformity in light intensity was achievable after the light beam has propagated through the input and output prism couplers. Improvement of the surface condition of the prism couplers and $LiNbO_3$ plate and the contact between them should result in a larger light beam aperture. The coupling efficiency, after propagating through the input and output prism couplers, is on the order of 20%. It is also seen that the mode structure of the diffracted beam is the same as that of the undiffracted beam. Thus, we conclude that no observable mode conversion was generated during the acoustooptic interaction with the device being studied.

The rf driving power of the device for a 50% diffraction efficiency was measured to be 200 mw, corresponding to an estimated acoustic power of at most 50 mw. This estimation is based on the assumption of a -3db electric-acoustic conversion loss and the well-known bidirectional property of the transducer. For the earlier version of the device referred to in Ref. 15, the corresponding rf driving power and the estimated acoustic power are 140 mw and 35 mw, respectively, with a device bandwidth of 60 MHz. Based on this rf driving power, the milliwatts per megahertz bandwidth of this new acoustooptic guided-light beam deflector/switch/modulator is among the smallest of those with previous devices. The milliwatt per megahertz bandwidth for this device is 1.1 mw/MHz and is 2.3 mw/MHz for the earlier version, while for the other most comparable device (at $\lambda = 1.15\ \mu$) described in Ref. 5 it is estimated to be 3.5 mw/MHz at a bandwidth of approximately 10 MHz. The efficient diffraction is attributed to a close match of the penetration depths, estimated to be about 10 μ,[16] between the guided-light waves and the surface acoustic waves. Optimization of both electrical and acoustical parameters of the device should further improve its performance.

In conclusion, we have experimentally demonstrated, for the first time, that a substantial increase in the bandwidth of an acoustooptic guided-light beam deflector/switch or modulator, can be achieved by employing multiple intersecting surface acoustic waves which are staggered in their operating frequency and tilted in their propagation direction. The measured performance figure of the device being studied, which employs two intersecting surface acoustic waves, is among the best of those having been achieved in recent years. It has been demonstrated that such a device configuration is both simple to design and to fabricate. In addition, we have observed that the measured Bragg bandwidth involving a single surface acoustic wave is much smaller than the calculated value based on the well established formula in bulk wave acoustooptic Bragg diffraction. The new technique introduced here will be essential for applications involving very wide bandwidths such as a guided-wave acoustooptic rf spectrum analyzer which requires a bandwidth of approximately 500 MHz[9] and high-speed switches for integrated/fiber optics terminals.

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FIGURE CAPTIONS

Fig. 1 Guided-Wave Acoustooptic Bragg-Diffraction from Two Intersecting Surface Acoustic Waves.

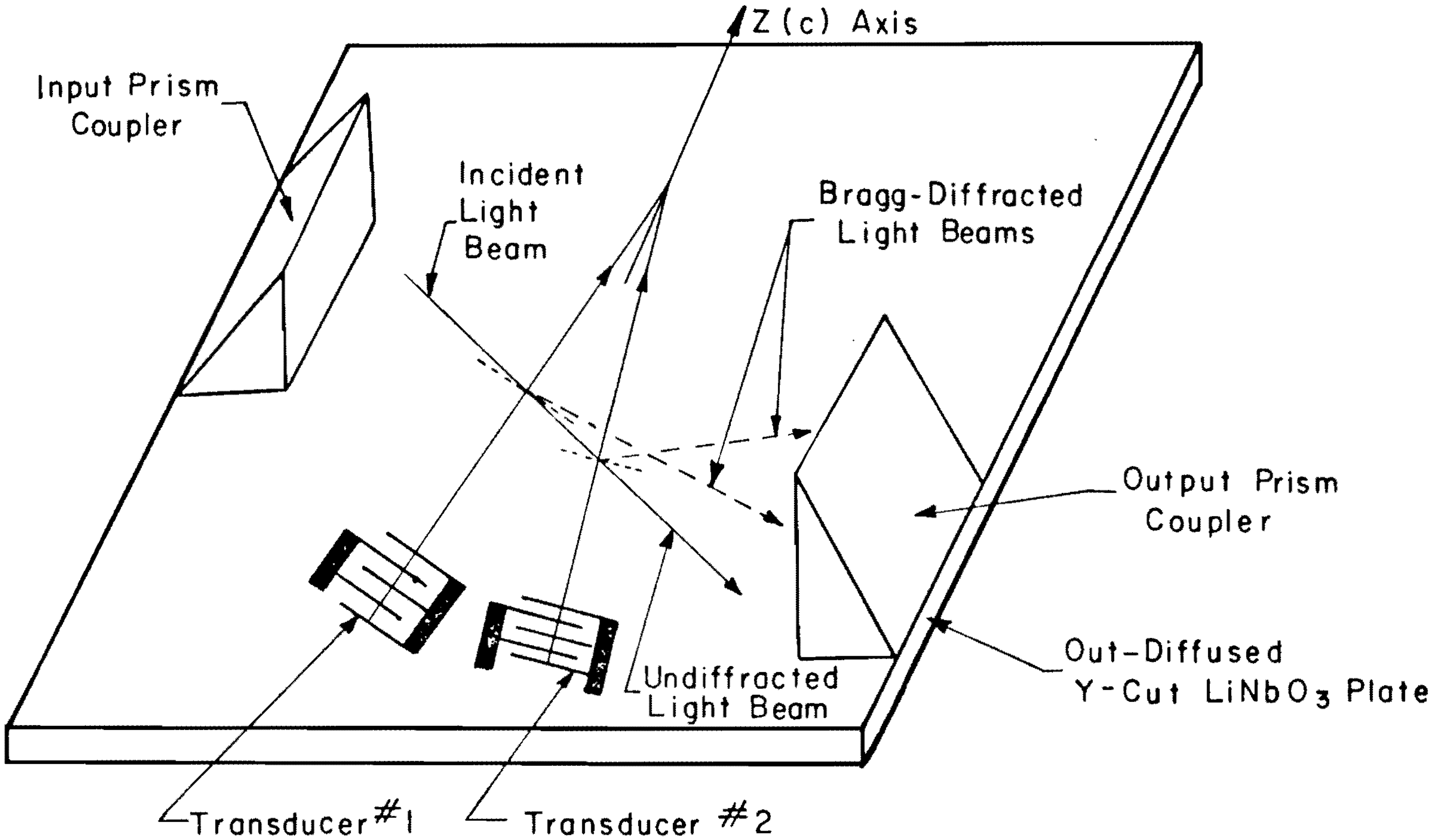
Fig. 2 (a) Electrical Responses of the Individual Transducers,

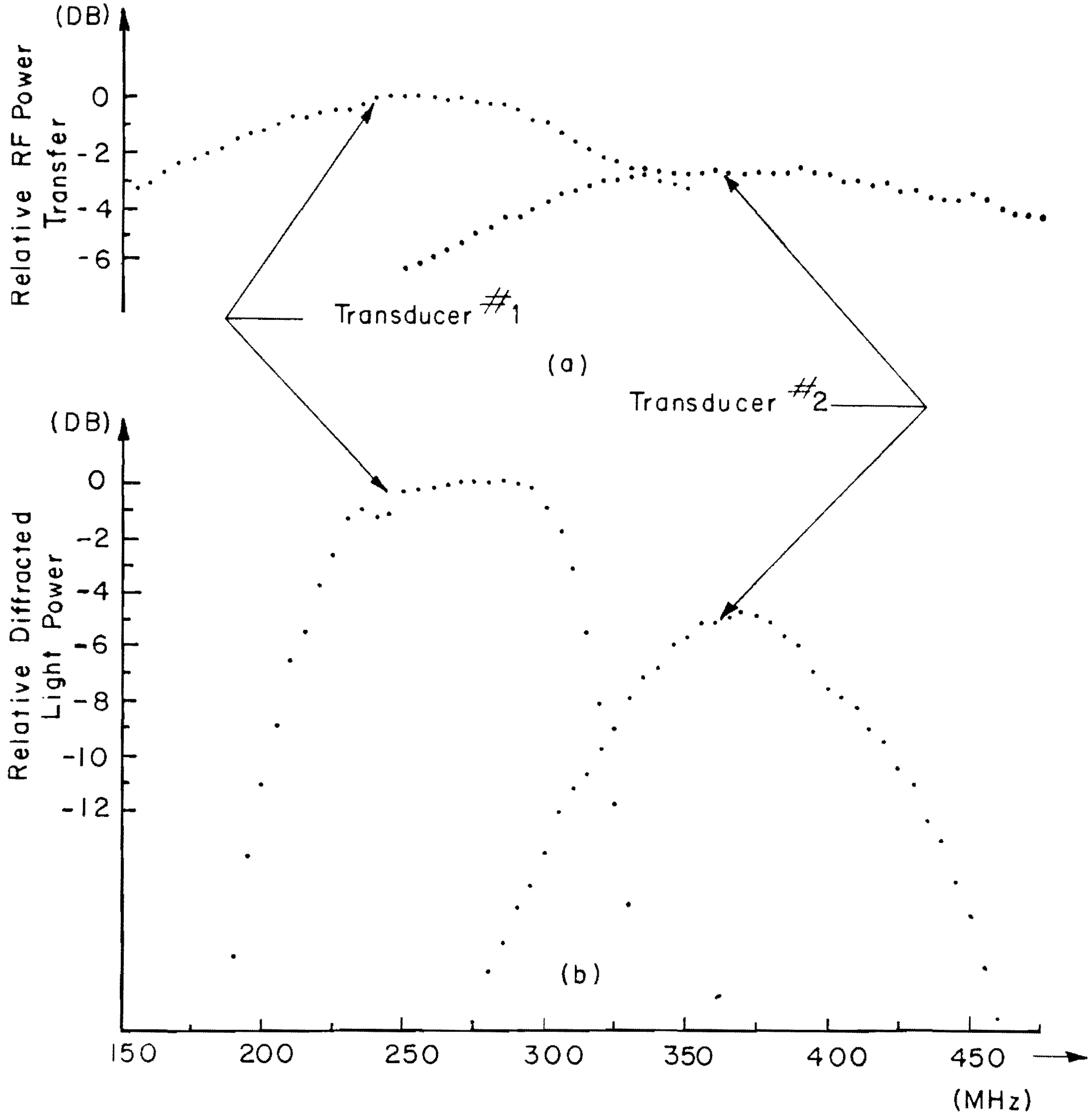
(b) Frequency Responses of the Bragg-Diffracted Light Power for the Individual Acoustic Beams

(c) Electrical Response of the Combined Transducer

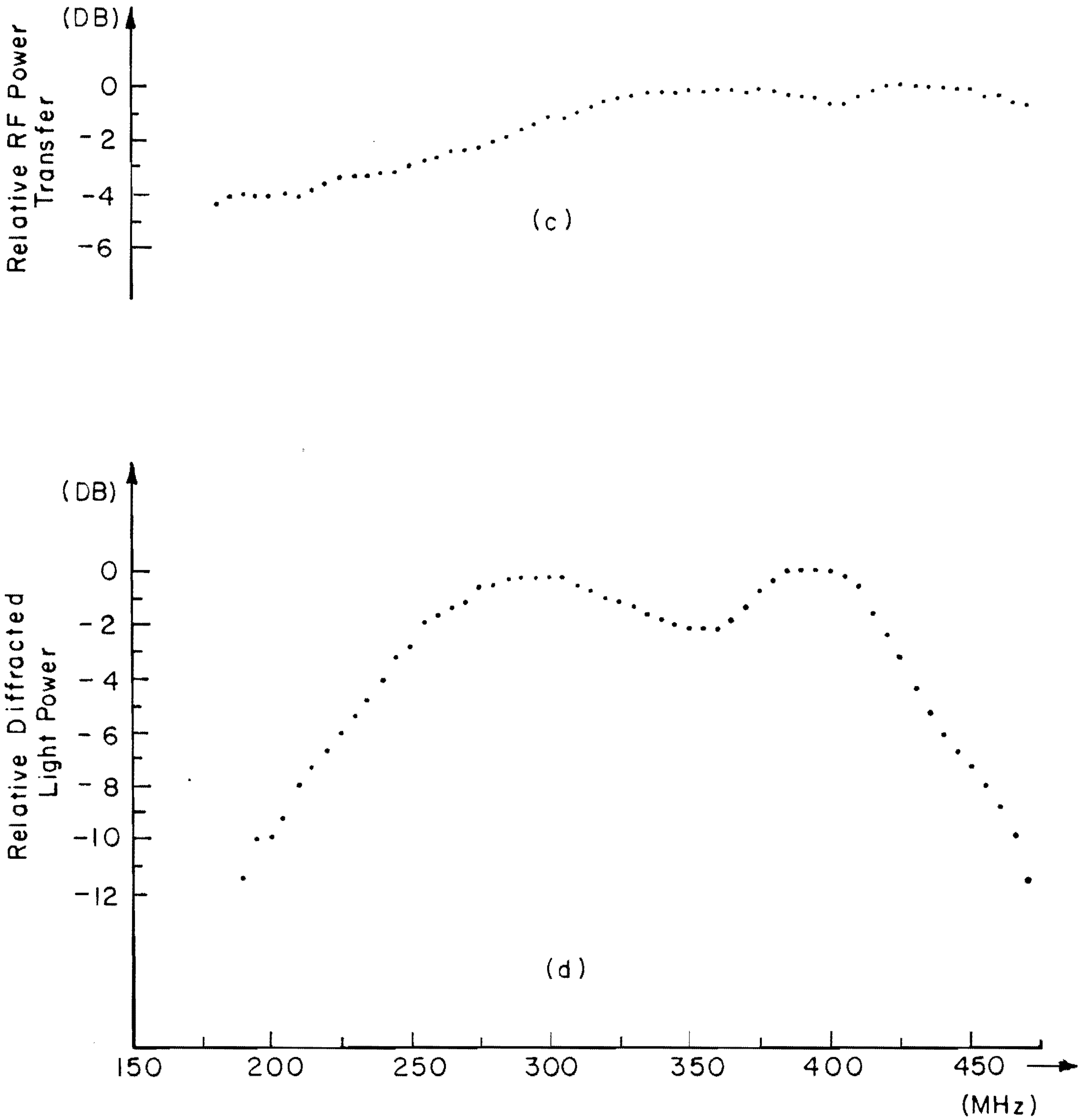
(d) Frequency Response of the Bragg-Diffracted Light Power for the Combined Acoustic Beam.

Fig. 3 Deflected Light Spot Positions as the Frequency of the Driving Signal is Varied: (a) Far-Field Spots; (b) Near-Field Spots.


Z (c) Axis
Input Prism Coupler
Incident Light Beam
Bragg-Diffracted Light Beams
Output Prism Coupler
Out-Diffused Y-Cut $LiNbO_3$ Plate
Undiffracted Light Beam
Transducer #1
Transducer #2



(DB)
Relative RF Power Transfer
0
-2
-4
-6
Transducer #1
(a)
Transducer #2
(DB)
Relative Diffracted Light Power
0
-2
-4
-6
-8
-10
-12
(b)
150
200
250
300
350
400
450
(MHz)


(DB)
Relative RF Power Transfer
0
-2
-4
-6
(c)
(DB)
Relative Diffracted Light Power
0
-2
-4
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-8
-10
-12
(d)
150
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350
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(MHz)